ASSESSMENT OF SAFETY AND ENVIRONMENTAL RISK IN MINES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
in
Mining Engineering

By

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CERTIFICATE

This is to certify that the thesis entitled **“ASSESSMENT OF SAFETY AND ENVIRONMENTAL RISK IN MINES”** submitted by Sri Sagar Pattnaik, Roll No. 10505015 in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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Date: **(Sagar Pattnaik)**

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ABSTRACT

Mining is a hazardous operation and consists of considerable environmental, health and safety risk to miners. Safety risk assessment is the systematic identification of potential hazards in workplace as a first step to controlling the possible risk involved. Unsafe conditions in mines lead to a number of accidents and cause loss and injury to human lives, damage to property, interruption in production etc. But the hazards cannot be completely obliterated and thus there is a need to define and reckon with an accident risk level possible to be presented in either quantitative or qualitative way.

Environmental risk assessment (ERA) involves the examination of risks resulting from natural events (flooding, extreme weather events, etc.), technology, practices, processes, products, agents (chemical, biological, radiological, etc.) and industrial activities that may pose threats to ecosystems, animals and people. Environmental health risk assessment addresses human health concerns and ecological risk assessment addresses environmental media and organisms. ERA is predominantly a scientific activity and involves a critical review of available data for the purpose of identifying and possibly quantifying the risks associated with a potential threat. Mining industries pose serious threat to environment by causing air and water pollution, land damages and socio-economic risks which need to be evaluated scientifically so as to minimize their long term implication to living and non-living systems

The objective of hazards and risk analysis is to identify and analyze hazards, the event sequences leading to hazards, and the risk of hazardous events. Many techniques, ranging from simple qualitative methods to advanced quantitative methods, are available to help identify and analyze hazards. The use of multiple hazard analysis techniques is recommended because each has its own purpose, strengths, and weaknesses. Some of the more commonly used techniques for risk assessment include: preliminary hazard analysis (PHA), failure modes and effects analysis (FMEA), hazard and operability studies (HAZOP), fault-tree analysis (FTA), and event-tree analysis (ETA).

Objectives of the Project:

- Understanding the basic concepts and methods of safety and environmental risk assessment.
- Fault tree analysis using Fault tree+11 software
- Development of programs in C++ for fire risk assessment in coal mines.
- Development of programs in C++ for closure risk assessment in mines.
- Case studies on risk assessment in coal mines of MCL

This project work discusses in detail the concept and steps in safety and environment risk assessment and their different approaches in risk assessment (qualitative and quantitative), various risk analysis techniques and important features of a safety management system for mines .It emphasizes the imperativeness to assess the risks from different mining operations and the need to adopt the cost effective suitable measures to prevent, eliminate and minimize risk.

Fault Tree+11 analysis programs for Microsoft Windows enables us to analyze the availability and reliability of both complex and simple systems and is easy and intuitive to use. Fault Tree+ 11 provides an integrated environment for performing fault tree analysis, event tree analysis and Markov analysis. In this project, mine fire is modeled using fault tree. A program for estimation of spontaneous fire risk potential in underground mines is carried out using TURBO C++. Another program was developed in C++ to compute closure risk factor for mines and to evaluate risk category. Data was collected from MCL mines to assess and quantify safety risk and suggest appropriate risk management.

Safety and environmental risk assessment is sine quo non for ensuring mining and miners safe .It is necessary to assess the risk from different mining operations and take cost effective suitable measures to prevent, eliminate and minimize risk .Both qualitative and quantitative risk approaches can be followed to assess the risk level .Risk analysis techniques like FTA, ETA AND HAZOP etc can be used as tools for study and understanding the risk levels more effectively and can aid in risk prevention and control.

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CHAPTER 1

1. INTRODUCTION

Mining is a hazardous operation and consists of considerable environmental, health and safety risk to miners. Safety risk assessment is the systematic identification of potential hazards in workplace as a first step to controlling the possible risk involved. Unsafe conditions in mines lead to a number of accidents and cause loss and injury to human lives, damage to property, interruption in production etc. But the hazards cannot be completely obliterated and thus there is a need to define and reckon with an accident risk level possible to be presented in either quantitative or qualitative way.

Environmental risk assessment (ERA) involves the examination of risks resulting from natural events (flooding, extreme weather events, etc.), technology, practices, processes, products, agents (chemical, biological, radiological, etc.) and industrial activities that may pose threats to ecosystems, animals and people. Environmental health risk assessment addresses human health concerns and ecological risk assessment addresses environmental media and organisms. ERA is predominantly a scientific activity and involves a critical review of available data for the purpose of identifying and possibly quantifying the risks associated with a potential threat. Mining industries pose serious threat to environment by causing air and water pollution, land damages and socio-economic risks which need to be evaluated scientifically so as to minimize their long term implication to living and non-living systems.

It is pertinent to assess environmental and safety risk in mines using appropriate methodology and tools to make mine environmentally harmless and safe. Statutory requirements also put mining companies to adopt systematic and proper risk assessment and will be the need of the present as well as in the future. This project is an attempt in this direction.

1.1 NEEDS FOR RISK ASSESSMENT

- ➢ Identify hazards–something with the potential to cause harm,
- ➢ Assess the likelihood, or probability, of harm arising from the hazard,
- ➢ Assess the severity of harm resulting from realization of the hazard,
- ➢ Combine assessments of likelihood and severity to produce an assessment of risk and
- ➢ Use the assessment of risk as an aid to decision making.

Different types of approaches for safety in mines, various tools and appropriate steps have to be taken to make mining safe and environment friendly .Keeping this in view, making workplace better and safer, the project work was undertaken.

1.2 OBJECTIVES

The objectives of the projects are:

- Understanding the basic concepts and methods of safety and environmental risk assessment.
- Fault tree analysis using Fault tree+11 software
- Development of programs in C++ for fire risk assessment in coal mines.
- Development of programs in C++ for closure risk assessment in mines.
- Case studies on risk assessment in coal mines of MCL.

CHAPTER 2

2. LITERATURE REVIEW

2.1 RISK NOMENCLATURE

Risk is the probability that a hazard will turn into a disaster. Risk can be said to be the chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental stressor. Now a stressor is any physical, chemical, or biological entity that can induce an adverse response which adversely affect specific natural resources or entire ecosystems, including plants and animals, as well as the environment with which they interact.

Risk is a combination of the frequency or probability of a specified hazardous event, and its consequence.

Two factors of significance:

* The potential consequences of any accident that may result from the hazard;

* The frequency (or probability) of such an accident.

Risk= severity (consequence) x frequency x exposure

Probability - likelihood that the particular hazard will result in a fire.
Severity - an estimation of how serious the potential problem might be in terms of harm to people and/or damage to property.

2.2 INTERPRETATION OF RISK CLASSES

Class I Intolerable risk

Class II Undesirable risk, and tolerable only if risk reduction is impracticable

Class III Tolerable risk if the cost of risk reduction would exceed the improvement gain

Class IV Negligible risk

Table 2.1 Risk rating criteria

Consequence	Exposure	Probability
Several Dead 5	Continuous 10	Expected/almost certain 10
One Dead 1	Frequent (Daily) 5	Quite possible/likely 7
Significant chance of Fatality 0.3	Seldom (Weekly) 3	Unusual but possible 3
One Permanent Disability 0.1	Unusual (Monthly) 2.5	Only remotely possible 2
Small chance of fatality 0.1	Occasionally (Yearly) 2	Conceived but unlikely 1
Many lost time Injuries 0.01	Once in 5 years 1.5	Practically impossible 0.5
One lost time injury 0.001	Once in 10 years 0.5	Virtually impossible 0.1
small injury 0.0001	Once in 100	Years 0.02

Risk = Consequence x Exposure x Probability Maximum Risk Rating = 500

Risks ≥ 20 to be referred to Management for Action

2.3 DEFINITION OF RISK ASSESSMENT

Risk Assessment is defined as:

"A process of analysis to identify and measure risks from natural hazards that affect people, property and the environment. This process can also encompass the assessment of available resources to address the risks."

Or A risk assessment is the systematic identification of potential hazards in the work place as a first step to controlling the possible risk involved.

Risk Assessment is a common first step in a risk management process. Risk assessment is the determination of quantitative or qualitative value of risk related to a concrete situation and a recognized threat

Risk assessment forms a crucial early phase in the disaster management planning cycle and is essential in determining what disaster mitigation measures should be taken to reduce future losses. Any attempt to reduce the impact of a disaster requires an analysis that indicates what threats exist, their expected severity, who, or what they may affect, and why. Knowledge of what makes a person or a community more vulnerable than another, added to the resources and capacities available, determines the steps we can take to reduce their risk.

Risk assessment is carried out in a series of related activities which builds up a picture of the hazards and vulnerabilities which explain disaster events. Information is first collected on the specific location, severity, duration and frequency of threats that are faced by a society. This is followed by an assessment of potential hazard impacts on the society's livelihoods, economy, infrastructure and key facilities, etc. The scale of these impacts will always be conditioned by those processes which either increase or decrease vulnerability, which may be economic, social, political or environmental.

Table 2.2 Severity Category Examples Specific to Mine Safety

	Consequences				
Likelihood	Very Low **1**	Minor **2**	Moderate **3**	Major **4**	Catastrophic **5**
A (Almost Certain)	**15** *(Significant)*	**10** *(Significant)*	**6** *(High)*	**3** *(High)*	**1** *(High)*
B (Likely)	**19** *(Moderate)*	**14** *(Significant)*	**9** *(Significant)*	**5** *(High)*	**2** *(High)*
C (Moderate)	**22** *(Low)*	**18** *(Moderate)*	**13** *(Significant)*	**8** *(High)*	**4** *(High)*
D (Unlikely)	**24** *(Low)*	**21** *(Low)*	**17** *(Moderate)*	**12** *(Significant)*	**7** *(High)*
E (Rare)	**25** *(Low)*	**23** *(Low)*	**20** *(Moderate)*	**16** *(Significant)*	**11** *(Significant)*

Risk assessment therefore has two central components:

1. **Hazard analysis**, understanding the scale, nature and characteristics of a hazard

2. **Vulnerability analysis**, the measuring of the extent to which people or buildings are likely to suffer from a hazard occurrence.

Any change in either of these two components will correspondingly effect a change in the nature or size of the risk faced. Once data has been collected and analyzed on both the threat and what is at risk to it, the information has to be passed on in an appropriate format to decision makers to determine levels of acceptable risk and what actions should be taken to reduce it. Decisions will then be made as to whether risk reduction measures should be initiated, what level of protection is required and whether there are other more pressing risks to address with finite resources.

Understanding risk and taking decisions is therefore a two part process involving both risk evaluation and risk assessment.

- **risk assessment** refers to the scientific quantification of risk from data and an understanding of the nature of the hazards and the vulnerable elements to it

- **risk evaluation** is the social and political judgments about the importance of various risks faced by individuals and communities.

Risk assessment is therefore mainly a scientific and *quantitative* activity which informs the decision making process. The utilization of the data provided and its incorporation into disaster reduction activities will then depend on risk evaluation; the appraisal or perception of the risk in co-ordination with other priorities and *qualitative* assessment of whether anything can be done to reduce that same risk. It is therefore logical that the more accurate the diagnosis of the problem and the resources available to meet it the better the decisions will be. Complexity of understanding the characteristics of the threats faced and the diverse nature of vulnerability a totally accurate and comprehensive picture will not always be possible.

2.3.1 Conducting risk assessment

The term risk refers to the expected losses from a given hazard to a given element at risk, over a future specified time period. In order to understand and to compare different risks, scientists and economists usually try to quantify them in terms of their probability of occurrence and secondly the potential damage and losses they might cause. This is done by using statistical analysis to predict the probability of future events and by gathering data on the effects of various hazards that cause the risk. This identification of effects and the understanding of the processes of disaster occurrence constitute the first steps in establishing a relationship between hazard and vulnerability in order to identify the risk.

By using past historical records and an analysis of scientific data estimates can be made of the likelihood of hazard occurrence and expected severity. When allied to estimates of what is vulnerable to various hazards risk can be defined in terms of the probability. i.e. the likelihood of losses and an estimation of the proportion of the population which will be affected.

The process of risk assessment is usually conducted in the following sequence:

1. **Hazard analysis:** Hazard information is needed on such matters as location, frequency, duration and severity of each hazard type. Risk assessment should be carried out, where possible, in relation to all the hazards in a given location.

2. **Vulnerability analysis:** Vulnerability analysis starts with creating an inventory of all elements that are 'at risk' to the identified hazards such as social groups, buildings, infrastructure, economic assets, agriculture etc. This is followed by an assessment of their susceptibility and an estimation of damage and losses. Vulnerability analysis includes an assessment of resources or capacities to meet and recover from hazardous events.

3. **Risk Evaluation and determining levels of acceptable risk:** Once data on the nature of the hazards and vulnerability has been collected, synthesized and analyzed by technical staff in the categories noted above it ideally has to be passed in an appropriate format to decision makers to enable them to determine levels of acceptable risk leading to levels of protection. These decisions will be made according to risk perception, knowledge of possibilities to reduce the threat and other priorities.

Part of this decision making process is determining acceptable levels of safety, i.e. what level of protection is required? For example, should shelter be built to resist an event, e.g. hurricane that recurs every 5, 20, or 100 years of such a magnitude that it would blow away all the houses around? A key feature of acceptability therefore is cost benefit trade off: to build a house that withstands a once a century very strong hurricane may cost ten times more than a house which will not, but which may last for ninety years.

Vulnerability assessment

Once knowledge is gained of the threats in existence, their expected severity and locations at risk, an understanding of what can be affected by these threats is needed. This activity is termed **vulnerability assessment** and is defined as:

“The analysis of the vulnerability of various sectors that are exposed to the natural hazards identified in the hazard analysis
exercises. The sectors include social, livelihoods, economic, physical assets, agriculture, political and administration.”

Vulnerability is the extent to which a community, structure, service or region is likely to be damaged or disrupted by the impact of a particular hazard. People’s lives and health are directly at risk from the destructive effects of hazards. Their incomes and livelihoods are also at risk because of the destruction of the buildings, crops, livestock or equipment which they depend on. Even if physical loss is avoided the effects on livelihood, etc., can last a long time and often previous levels of existence are not re-attained, for example a fire in an informal market may not kill anybody yet may destroy goods and therefore livelihoods of market traders. Thus vulnerability assessment aims not just to recognize who is immediately affected but also who is most or least able to recover from their disasters.

The objective of vulnerability assessment is in particular to identify who is most vulnerable and why. The concept of vulnerability can be assessed at a variety of levels and from diverse perspectives. The closer the analysis gets to the fundamental causes rather than the symptomatic aspects of vulnerability, the more difficult and complex vulnerabilities are to address. However, the more fundamental the vulnerability addressed, the more hazard resistant the vulnerable group is likely to become as a result.

Each type of hazard puts a different set of elements at risk. Most of disaster mitigation work is focused on reducing vulnerability, and in order to do so development planners need an understanding and indication of which elements are most at risk from the principal hazards which have been identified. Vulnerability assessment to hazards usually
takes place in the following two stage sequence:

1. Making an inventory of what is at risk: Once the hazards in any location or area have been identified it is necessary to find out what may be affected by them. Thus base line data is required on the following;

- population; age, gender, health
- livelihoods; types, locations
- local economies
- agriculture and fisheries
- buildings
- infrastructure
- Cultural assets (i.e. libraries, museums, historic buildings etc.)
- local institutions

2. Assessing the vulnerability of elements at risk: After an inventory has been made of the elements at risk further examination has to be made of how they will be affected by hazards to make an assessment of the risk. It should be noted that whilst a quantification of the elements existing in any location is relatively straightforward, an assessment of how they will be affected in a hazard event is harder to assess. It is important to note that it is often the case that the 'intangible' aspects of vulnerability will be as important as the quantifiable aspects. These should include the evaluating of socio-economic vulnerability and individual or societal "coping mechanisms" as well as support systems which allow some people to cope with the impact of a hazard and recover from them comparatively faster. The most difficult vulnerabilities to address are based on exclusion from social, economic and political systems. These vulnerabilities may reflect characteristics such as race, gender, religion, ethnicity, social class, age etc. These most fundamental vulnerabilities limit people's access to resources, opportunities, services, information and ultimately deny people choice in control over their lives. Vulnerability assessment is therefore another complex data collection process to determine elements 'at risk'. These include social, economic and natural and physical factors. It is always a 'site-specific' process with a concern for unique characteristics of a local situation and will always require local expertise and experience.

2.4 BENEFITS OF RISK ASSESSMENT

- To enable control measures to be devised,
- To gain an idea of the relative importance of risks,
- To take decisions on controls which are cost effective and appropriate,
- The identification of potential future disasters,
- The exploration of quality and safety failures before anyone is hurt, and
- The development of a safety culture.

2.5 SAFETY RISK ASSESSMENT

2.5.1 Introduction

The risk assessment portion of the process involves three levels of site evaluation:

1) Initial Site Evaluation,

2) Detailed Site Evaluation, and

3) Priority Site Investigations and Recommendations.

The risk assessment criteria used for all levels of site evaluation take into account two basic factors:

1) The existing site conditions and

2) The level of the traveling public's exposure to those conditions.

The Initial Site Evaluation and Detailed Site Evaluation both apply weighted criteria to existing information and information obtained from one site visit. The Initial Site Evaluation subdivides the initial inventory listing of sites into 5 risk assessment site groups. The Detailed Site Evaluation risk assessment is then performed on each of the three highest risk site groups in the order of the group priority level of risk. The result of the Detailed Site Evaluation process is a prioritized listing of the sites within each of the three highest risk site groups.

2.5.2 Conducting a Safety/Risk Assessment in Six Steps

1) The group that will conduct the analysis is chosen first,

2) The geographic area to be included is defined,

3) All of the possible hazards that exist in the area selected for study is included,

4) The Risks are to be evaluated this step,

5) Hazard Ratings are used during resource allocation,and

6) The task of risk assessment is an on-going activity.

2.6 QUALITATIVE RISK ANALYSIS

The assessment of risk can be qualitative or quantitative. The latter requires significant specialist effort, and therefore, the qualitative assessment is often used as being the simpler of the two.

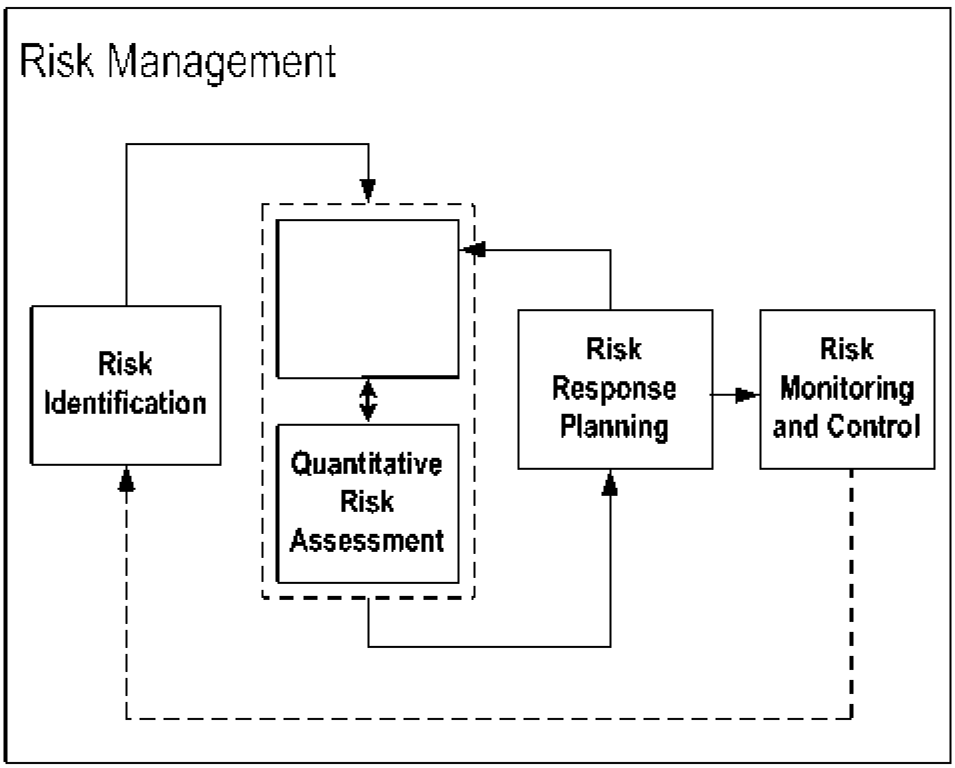


Figure 2.1: Risk Management Plan

Having identified a range of risks we now need to consider which the most serious risks are in order to determine where to focus out attention and resources. We need to understand both their relative priority and absolute significance.

People generally are not inherently good at analyzing risk. We tend to take decisions swayed by our emotional response to a situation rather than an objective assessment of relative risk. Given half a chance most of us will believe what we want to believe and selectively filter out information that does not support our case. We are similarly bad at looking at probability in a holistic way. People generally focus on risks that have occurred recently even though another risk may have happened exactly the same number of times over the last five years.

We must nonetheless accept that most of the risk analysis done in our environment will be of a qualitative nature. Few of us have the skills, time or resources to undertake the kind of quantitative modeling that goes on in major projects in the commercial sector. This section aims to show that by taking a disciplined and structured approach it is possible to improve the objectivity of your analysis without getting into complex calculations or needing specialist software tools.

In deciding how serious a risk is we tend to look at two parameters:

- Probability - the likelihood of the risk occurring
- Impact - the consequences if the risk does occur

Impact can be assessed in terms of its effect on:

- Time
- Cost
- Quality

There is also a third parameter that needs to be considered:

- Risk proximity - when will the risk occur?

Proximity is an important factor yet it is one that is often ignored. Certain risks may have a window of time during which they will impact. A natural tendency is to focus on risks that are immediate when in reality it is often too late to do anything about them and we remain in 'firefighting' mode. By thinking now about risks that are 18 months away we may be able to manage them at a fraction of the impact cost. Another critical factor relating to risk proximity is the point at which we start to lose options. At the start of a project there may be a variety of approaches that could be taken and as time goes on those options narrow down. We said earlier that risk management is about making better decisions. Very often in the education sector we put off taking decisions until the options disappear and there is only one way forward.

Assessment of both probability and impact is subjective but definitions need to be at an appropriate level of detail for the project. The scale for measuring probability and impact can be numeric or qualitative but either way you must understand what those definitions mean. Very often the scale used is High, Medium and Low. This is probably too vague for most projects. On the other hand a percentage scale from 1-100 is probably too detailed.

Use of enough categories is advised so that anyone can be specific but not so many that someone wastes time arguing about details that won't actually affect their actions. Experience suggests that a five-point scale works well for most projects. A suggested scale is:

Table 2.3 Five point scale for risk assessment

Scale	Probability	Scale	Impact
Very Low	Unlikely to occur	Very Low	Negligible impact
Low	May occur occasionally	Low	Minor impact on time, cost or quality
Medium	Is as likely as not to occur	Medium	Notable impact on time, cost or quality
High	Is likely to occur	High	Substantial impact on time,

			cost or quality
Very High	Is almost certain to occur	Very High	Threatens the success of the project

2.7 QUANTITATIVE APPROACH-RISK ASSESSMENT

Quantitative or risk analysis (QRA) is useful because quantification of risk in terms of likelihood of the event and the severity of the consequences provides the system's manager with an important decision-making aid. However, the Quantitative Risk Analysis (QRA) provides significant benefits as it not only helps to identify and rank the risk contributors, but also assists in setting priorities for directing the risk reduction efforts to achieve optimal outcome.

The QRA integrates all the individual technical studies of the Safety Assessment and evaluates the risk from operations to personnel. The risk levels calculated are then evaluated against performance standards to ensure ALARP levels are reached.

The main limitation of QRA is the lack of adequate frequency data for initiating event for the MAE (e.g. fire or drilling into misfired hole), and dependency on human error failure probability, which is not available for the mining industry.

2.7.1 Risk Evaluation

There are no formally established regulatory criteria for risk to personnel in the mining industry. Individual organizations have developed criteria for employee risk, the concepts originally arising from the chemical process industries and oil and gas industries.

Because of the uncertainties associated with probabilistic risk analysis, used for quantification of risk levels, the general guiding principle is that the risk be reduced to a level considered As Low As Reasonably Practicable2.2 (ALARP). It is not easy to define what ALARP is, where we stop the risk reduction process.

Figure illustrates the risk criteria. It has three tiers:

a. A Tolerable region where the risk has been shown to be negligible, and comparable with everyday risks such as travel to work.

b. A middle tier, where it is shown the risk has been reduced to As Low As Reasonably Practicable level and that further risk reduction is either impracticable or the cost is grossly disproportionate to the improvement gained. This is referred as the ALARP region.

c. An ―Intolerable region where the risk cannot be justified on any grounds. The ALARP region is kept sufficiently broad to allow for flexibility in decision making and allow for positive

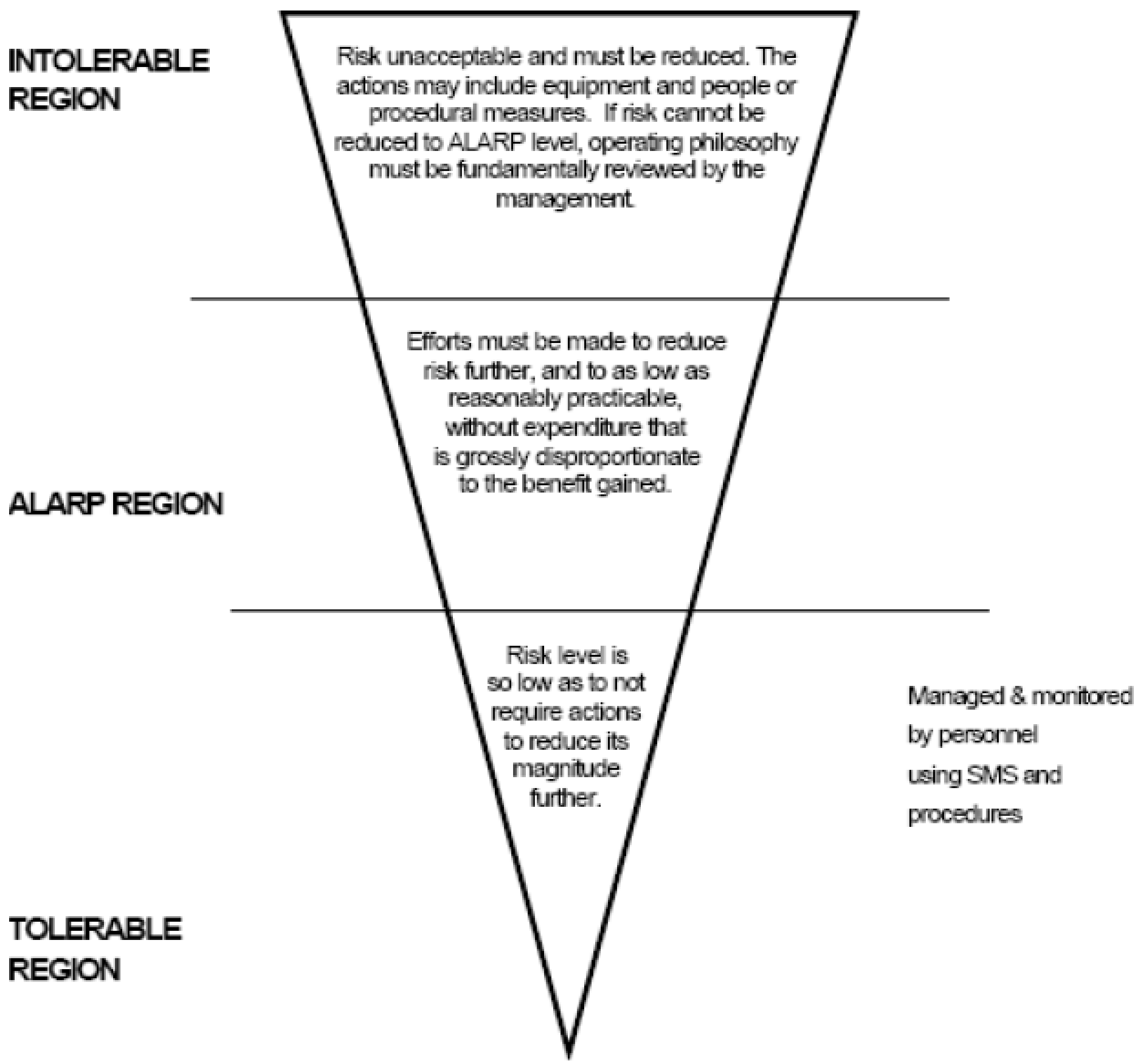


Figure 2.2 ALARP

management initiatives, which may not be quantifiable in terms of risk reduction. Some organizations in the process industries and oil and gas industries have set numerical criteria for risk as demarcation between the tiers. It is not appropriate to apply the criteria from one industry to another, as the nature of the operations and types of risks are entirely different.

For a well managed mine site, the risk values for underground mining are expected to fall within the ALARP range. Therefore a demonstration of adequacy of control measures as part of overall ALARP demonstration is crucial.

2.8 RISK ANALYSIS METHODOLOGIES

2.8.1 Introduction

The objective of hazards and risk analysis is to identify and analyze hazards, the event sequences leading to hazards, and the risk of hazardous events. Many techniques, ranging from simple qualitative methods to advanced quantitative methods, are available to help identify and analyze hazards. The use of multiple hazard analysis techniques is recommended because each has its own purpose, strengths, and weaknesses. Some of the more commonly used techniques include preliminary hazard analysis (PHA), failure modes and effects analysis (FMEA), hazard and operability studies (HAZOP), fault-tree analysis (FTA), and event-tree analysis (ETA). Considerations in analyzing risk include.

- Investigating the frequency of particular types of disasters (often versus seldom).
- Determining the degree of predictability of the disaster.
- Analyzing the speed of onset of the disaster (sudden versus gradual).
- Determining the amount of forewarning associated with the disaster.
- .Estimating the duration of the disaster.

2.8.2 Comparison of Methods and Discussion

Successful risk management hinges on comprehensive and detailed hazard mapping and understanding of possible consequences. No specific risk analysis method should be chosen until relevant hazards have been clarified. A summary comparison of hazard sources from the described high-risk industries is attempted .The mining industry seems so different to most other sectors, yet it utilizes a variety of technologies from other often hazardous industries and in so doing has Involuntarily added entirely new and previously unknown hazards (and untried solutions) to its own suite of issues, quite often at a scale much larger than found in thek, parent industry. An example is the ongoing application of computer and software based technologies across the entire operation, particularly in safety critical applications. This overall trend will continue and considerably more emphasis and research needs to be applied to the elimination of hazards arising from this area and interaction with other systems, including the mineworker. Mining operations remain relatively people intensive and considerable effort should be applied in evaluating and improving aspects of human reliability. Work related illness can have its origins in classical OH+S issues such as exposure to chronic health hazards eg dust and chemical reagents, but many mining disasters have shown to be governed by the inherent technical risks associated with mining methods and the equipment and plant used. Apart from the shear size and magnitude of many mining operations and its equipment, the sector is also a major consumer of hazardous chemicals and products such as fuels, explosives and chemical reagents both for the mining process and beneficiation stages. Accidents associated with these in the past have caused both significant loss of life, disruption to operations and considerable and long-term destruction of the environment.

3) The layout of many mining operations is far from static and changes continuously. Operations, either as open-cuts, or underground mines or a combination of both have the scope to extend over large areas in often-inhospitable regions. All mines and operations are exposed to the danger of fire and explosions, with underground mines, particularly coal mines being extremely vulnerable and endangered by the effects offices and explosions. Variable geological conditions and the severity of the working environment have fundamental bearing on the operation and influence much of the activities directly in terms of maintenance and administration of the mine. Hazard identification usually establishes what risk assessment techniques should bemused and care needs to be taken in the selection of a technique, as similar techniques may not necessarily yield the same results .Risk assessment techniques may be either ‘subjective – qualitative’ or ‘objective –quantitative’ and both streams, ideally in combination can be very effective in the

process of hazards management. The mining industry is now familiar with the use of qualitative techniques, but there i as growing recognition of the value and effectiveness of quantitative studies particularly when assessing system hazards. Some quantitative techniques such as Fault Tree Analysis are ideally suited for assessments of large electro-mechanical systems and effects of human unreliability. Results from such studies can be used by safety, maintenance and operations management to good effect. However, use of quantitative techniques will require a more disciplined approach to recording and interpreting incident, accident and maintenance information to provide accurate and auditable inputs to those studies.

4) Qualitative techniques are comparatively cheap and readily applied but are unable to provide numerical estimates and therefore relative ranking of identified risks. Semi quantitative techniques allow some relative risk ranking, but these techniques are still unable to provide detailed assessments of system safety, effects of common cause failures and redundancy features. Similarly neither can effectively be used in the prediction of low frequency high consequence events – i.e. catastrophic risks. Quantitative methods overcome these shortfalls and are ideally applied where system safety and criticality is to be assessed. Catastrophic risks can be assessed using Fault Tree and Event Tree methods, ideally as part of a probabilistic risk analysis (PRA) provided reliable input data exists and numerical results can be used in estimating the likely range of risks to both employees, plant, society and the environment. Result scan also be used in cost benefit studies and demonstration that risks are ‘ as low as reasonably practicable’ (ALARP) can be supported defensively only by quantitativeanalysis.Truly probabilistic methods such as ‘first order reliability methods’ (FORM) are the most complex type of RA, and its advantage over any other method is the ability not only to successfully cope with the statistical uncertainty in the data but also use it to its advantage. Results from a FORM evaluation also provide further information on system vulnerability as a function of input variables. Analysis utilizing Monte Carlo (MC) techniques is more commonplace than FORM and has found widespread acceptance in many professions such as engineering and finance. However, MC methods lack some of the direct leverage that FORM provides for engineering solutions. A methods should be chosen, not just based on the hazard, but also after consideration of the capabilities of each technique as each may provide different outputs (or parameters) that may be particularly useful towards the solution of theproblem.Such outputs could be simple lists of individual failures (HAZOP, ‘What

if' etc), or numerical estimates of system failure probabilities (FTA), listings of event scenarios and their likelihoods (ETA, PRA) or numerical system failure probabilities and sensitivities to input variables (FORM).

5) FORM methods in particular also provide numerical estimates of the most likely failure scenario (the design point) which comprises a listing of all input variables and their estimates at the point of system failure. FORM has the added advantage that it is able to synthesize failure data (which is usually scarce) from basic engineering data through the adaptation of design calculations that can then be used to supplement other techniques such as FTA.

Table 2.4: Hazards characteristics and effects for mining industry

Hazards characteristics and effects	*Mining industry*
Single Concentrated Hazard Sources	Often – Explosives magazines, fuel and chemical reagents storage, transportation of blasting materials throughout the mine
Distributed Sources of Hazards	Always – throughout the mine – geological, environmental, mechanical
Chemical Toxicity	Often – beneficiation plants, reagent mixing plants, tailing dams, chronic ill health effects well documented for mining sector
Fires	Often – mobile and fixed equipment, beneficiation plants, electrical installations, fuel and tyre storage extreme fire if fire underground
Explosions	Sometimes – results from fires, accidents from blasting or preparation of blasting agents, fuel storage, extreme risk if fire underground

Radioactivity Rarely	Rarely – except for uranium mines and associated beneficiation plants
Changing Configuration	Always – transportation of ore and waste materials, different ground conditions as mine progresses
Human Error	Important
Environmental Pollution potential	Considerable – regional & national, short, medium and long term
Design Considerations & physical characteristics	Complex processes with few redundancies– considerable exposure to inherent hazards (geological conditions) – facilities both above and underground – usually in remote locations. Very vulnerable to natural events – cyclones, flooding etc
Est. fatalities - within Plant	<<100
Est. fatalities – external to plant	Very unlikely

2.8.3 RISK ANALYSIS METHODS

We will be analyzing four methods here:-

2.8.3.1 *FTA (Fault tree analysis)*:

Fault tree analysis is a logical, structured process that can help identify potential causes of system failure before the failures actually occur. This analysis method is mainly used in the field of safety engineering to quantitatively determine the probability of a safety hazard Fault tree analysis is a logical, structured process that can help identify potential causes of system failure before the failures actually occur. This analysis method is mainly used in the field of safety engineering to quantitatively determine the probability of a safety hazard. Fault tree analysis is a systematic safety analysis too that proceeds deductively from the occurrence of an undesired event (accident) to the identification of the root causes of that event. One recurring mine safety problem—a dozer falling into a void over a draw point on a coal surge pile—was analyzed using available, inexpensive fault tree programs on a personal computer. The analysis identified basic and intermediate events that led to the burial of the dozer and graphically depicted the interrelationship between these various subordinate events as well as the various chain of events leading up to the primary event. A sensitivity analysis on these probabilities showed which events had the greatest influence on dozer burial in a coal surge pile.

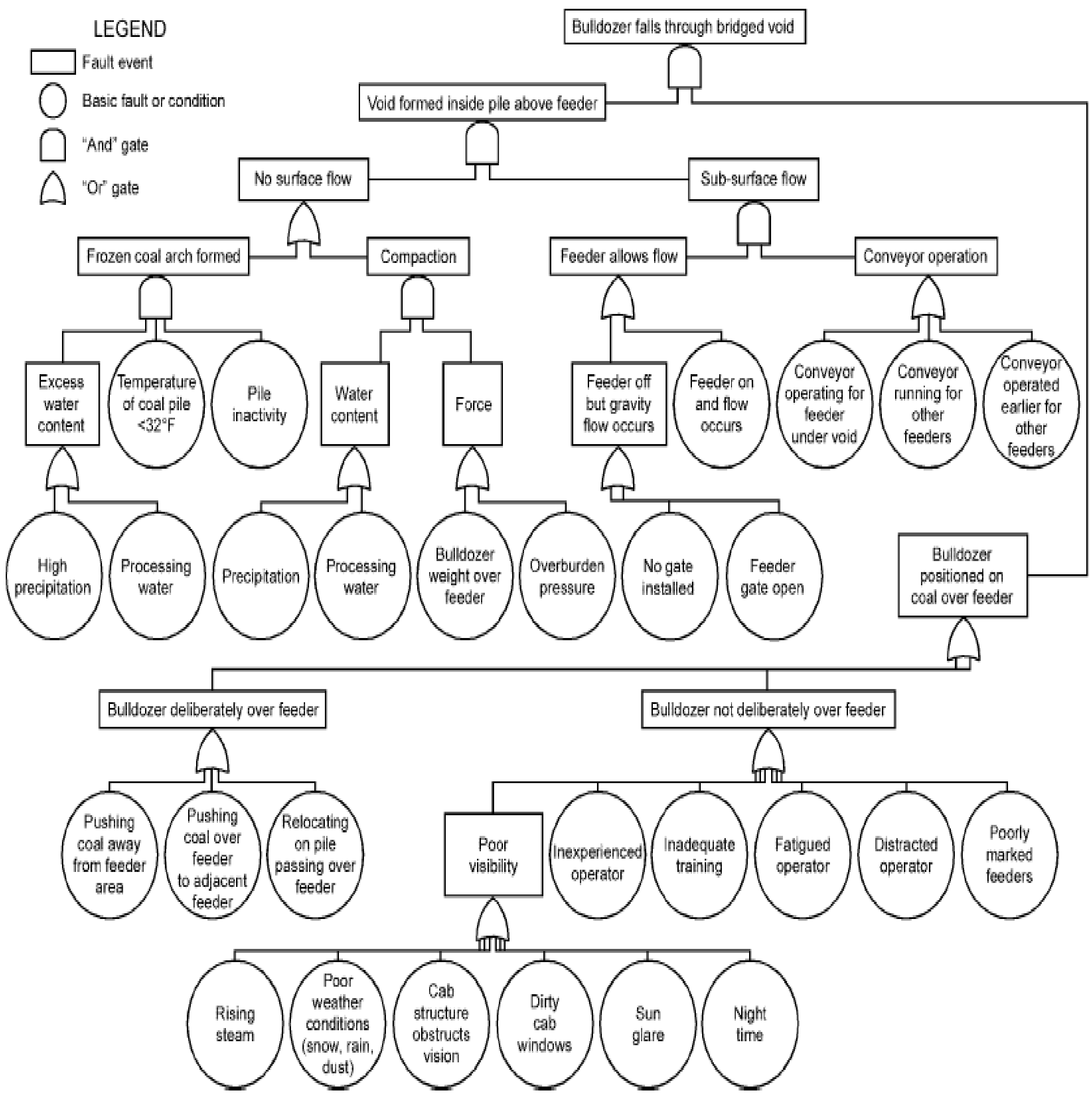


Figure 2.3 Fault tree analysis(*Dozer burial in coal surge piles*)

Advantages:

• Identifies multiple failures,

• Identifies multiple events and sequences leading to a hazard,

• Identifies common causes,

• Provides valuable documentation to aid investigations of mishaps, and

• Suitable for hardware or software.

Disadvantages:

• Can become time-consuming if trees grow very large.

• Not suited for timing (dynamic) situations.

The fault tree is constructed by first identifying the top fault event, which, in this case, is a dozer falling into a void on a coal surge pile. A secondary event (A) that contributes directly to the top fault event occurs when the dozer operator positions the dozer directly over the hazardous feeder zone. The only other secondary event (B) required to trigger the top fault event is the formation of a void within the coal pile between the feeder and the surface. These two secondary events are further broken down to determine the root causes. Figure 2.3 shows the completed fault tree for a dozer falling into a void on a coal surge pile. In secondary event A, where the dozer is driven directly over or near the feeder, the question arises as to why the operator put him- or herself in this hazardous position. Either the operator has unintentionally driven over the feeder or feels confident that no void exists at the feeder. For the former, six reasons were proposed: poor visibility, inexperience, inadequate training, fatigue, distractions, and inadequate feeder markers. In this fault tree, only the poor visibility event was further explored. Six reasons were then developed for the poor visibility response: that the dozer was being driven at night, the cab windows were dirty, the sun caused a glare on the windows, the cab structure obstructed vision, weather conditions (such as rain, snow, or blowing dust) were poor, and steam was rising from the pile. If the operator had intentionally positioned the dozer over the feeder, confident that no void existed but putting him- or herself at risk, the only feasible reason was to save time by taking a more direct route during dozing. Three types of actions that favor a direct route are driving over or backing up to the hazardous feeder zone while pushing coal away from the feeder area when expanding the pile, pushing coal to an active feeder but passing over an adjacent feeder or backing up to the hazardous zone, and passing over a feeder when relocating and moving onto or off the pile .In secondary event (B), a void is formed over a feeder when there is subsurface flow at the same time there is no surface flow. Subsurface flow or flow from the feeder happens normally when the conveyor is on and the feeder allows flow. If the feeder is energized and the belt is on, flow will occur. Flow may also occur when the feeder is turned off if there are changes in coal properties, such as the angle of repose of the coal. (A safety gate may be installed to prevent such flow. However, an additional condition maybe set up if a safety gate is installed but is open.)

A contradiction is faced in the question “How can surface flow not occur when subsurface flow occurs?” A basic understanding of flow in a surge pile is important for understanding why surface flow does not take place even when there is subsurface flow. A typical opening dimension of 5 by 5 ft at the base of a pile will only allow vertical movement in a column of coal having the same dimensions. As the flow column reaches the surface, a void or hole will form. The upper sides of the hole will fail at the angle of repose as the column is drawn down. However, if the upper layer of coal is held together by cohesive force acting between coal particles, then the strength of this layer may prevent surface flow, and a void will form below the surface to a depth comparable to the amount of coal drawn from the feeder. In the fault tree analysis, two cohesive conditions were proposed: simple compaction and binding of coal particles by freezing water. In order for freezing water to bind the coal together, a water source is needed. Because a coal surge pile is open to the elements, rain and/or snow will provide that source. In clean coal piles, moisture will also be left over from the cleaning operation. During fall, winter, and spring, low temperatures may result in freezing water binding the coal particles so no surface flow can take place, even though above-freezing temperatures are present in the coal below the surface. Time is also a factor, and an inactive pile will be more prone to surface freezing. Compaction of coal near the surface of the pile can also prevent surface flow. Compaction requires that a force be applied over an area of the coal. The degree of compaction will vary depending on water content. If no moisture is present, then the likelihood of cohesive strength and therefore compaction diminishes. As discussed above, moisture may come from rain or snow or from the cleaning plant. The force applied to the coal at the surface over the feeder is most likely the result of the weight and vibration of the dozer. A less likely source is coal overburden pressure. According to the MSHA accident report for the fatality in November of 1998, compacted layers were observed overhanging less-compacted layers below in the void .Here again; the dozer must be positioned over the feeder to compact the coal.

Quantification of the Fault Tree

The qualitative construction of the fault tree shows the interdependence of events. It does not, however, depict the amount of influence the basic events have on the top fault event. A quantified fault tree does show the influence of a basic event on the top fault event and ranks the basic events in terms of this influence. The practicality of a fault tree approach becomes apparent in such a construction. A quantifiedfault tree is a strategy, a plan of action, for it shows which events have the most influence on the occurrence of the top fault event and therefore which events should bead dressed first in any type of efficient and effective remedial action. A quantified fault tree analysis can show where to act first to generate the most results for the least amount ofwork.The first step in quantifying a fault tree is to assign initial probabilities to the basic events. This step was taken by gathering information from a focus group familiar with coal surge piles. The group was given the graphic of the fault tree and then asked to assign qualitative ratings for the probabilities of occurrence of the basic events using their experience and best judgment.

2.8.3.2 ***Event Tree Analysis***

An event tree analysis (ETA) is an inductive procedure that shows all possible outcomes resulting from an accidental (initiating) event , taking into account whether installed safety barriers are functioning or not, and additional events and factors. Or An **event tree** is a graphical representation of the logic model that identifies and quantifies the possible outcomes following an initiating event By studying all relevant accidental events (that have been identified by a preliminary hazard analysis, a HAZOP, or some other technique), the ETA can be used to identify all potential accident scenarios and sequences in a complex system. Design and procedural weaknesses can be identified, and probabilities of the various outcomes from an accidental event can be determined. **Event tree analysis** provides an inductive approach to reliability assessment as they are constructed using forward logic. Fault trees use a deductive approach as they are constructed by defining TOP events and then use backward logic to define causes.

Event tree analysis (Fig. 2.3) and fault tree analysis are, however, closely linked. Fault trees are often used to quantify system events that are part of event tree sequences. The logical processes employed to evaluate event tree sequences and quantify the consequences are the same as those used in fault tree analyses.

Advantages:

• Well suited for single events with multiple outcomes

• Suited for high risks not amenable to simpler analysis methods

Disadvantages: • Trees can grow large very quickly

• Probabilities may be difficult to estimate

• Can be extremely time-consuming

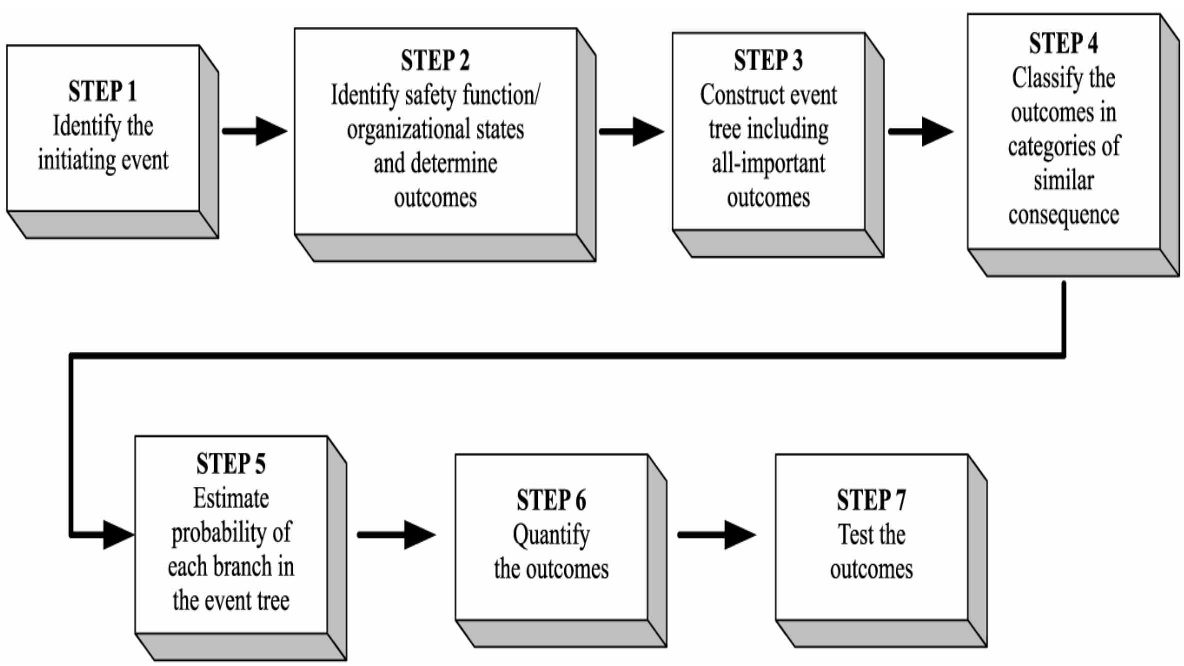


Figure 2.4 Event tree analysis

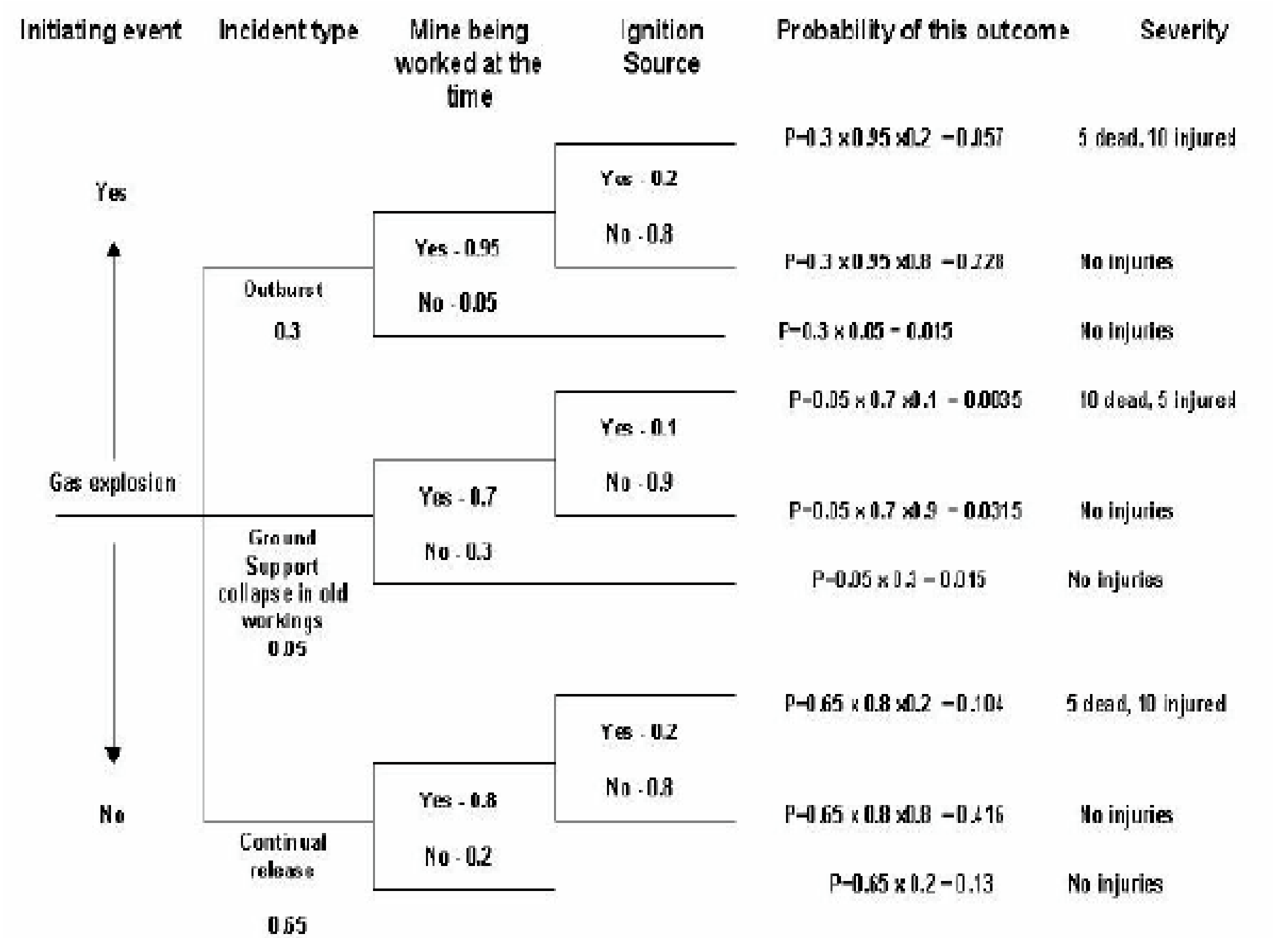
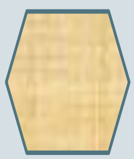
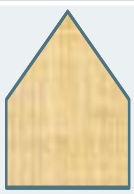


Fig 2.4 Event tree analysis for gas explosion

2.8.3.3 HAZOP

A HazOp study identifies hazards and operability problems. The concept involves investigating how the plant might deviate from the design intent. If, in the process of identifying problems during a HazOp study, a solution becomes apparent, it is recorded as part of the HazOp result; however, care must be taken to avoid trying to find solutions which are not so apparent, because the prime objective for the HazOp is problem identification. Although the HazOp study was developed to supplement experience-based practices when a new design or technology is involved, its use has expanded to almost all phases of a plant's life. HazOp is based on the principle that several experts with different backgrounds can interact and identify more problems when working together than when working separately and combining their results.

Table 2.5 Logic gates for HAZOP

	EVENT OR FAULT
	BASIC EVENT OR FAULT
	INCOMPLETE EVENT OR FAULT
	INHIBIT GATE
	TRIGGER EVENT
	AND GATE
	OR GATE

The "Guide-Word" HazOp is the most well known of the HazOps. However, several specializations of this basic method have been developed. These specializations will be discussed as modifications of the Guide-Word approach, but they are not to be regarded as less useful than the Guide-Word approach. Indeed, in many situations these variations may be more effective than the Guide-Word approach. The HazOp concept is to review the plant in a series of meetings, during which a multidisciplinary team methodically ”brainstorms" the plant design, following the structure provided by the guide words and the team leader's experience.

The primary advantage of this brainstorming is that it stimulates creativity and generates ideas. This creativity results from the interaction of the team and their diverse backgrounds. Consequently the process requires that all team members participate (quantity breeds quality in this case), and team members must refrain from criticizing each other to the point that members hesitate to suggest ideas.

The team focuses on specific points of the design (called "study nodes"), one at a time. At each of these study nodes, deviations in the process parameters are examined using the guide words. The guide words are used to ensure that the design is explored in every conceivable way. Thus the team must identify a fairly large number of deviations, each of which must then be considered so that their potential causes and consequences can be identified.

The best time to conduct a HazOp is when the design is fairly firm. At this point, the design is well enough defined to allow meaningful answers to the questions raised in the HazOp process. Also, at this point it is still possible to change the design without a major cost. However, HazOps can be done at any stage after the design is nearly firm. For example, many older plants are upgrading their control and Instrumentation systems. There is a natural relationship between the HazOp deviation approach and the usual control system design philosophy of driving deviations to zero; thus It Is very effective to examine a plant as soon as the control system redesign is firm

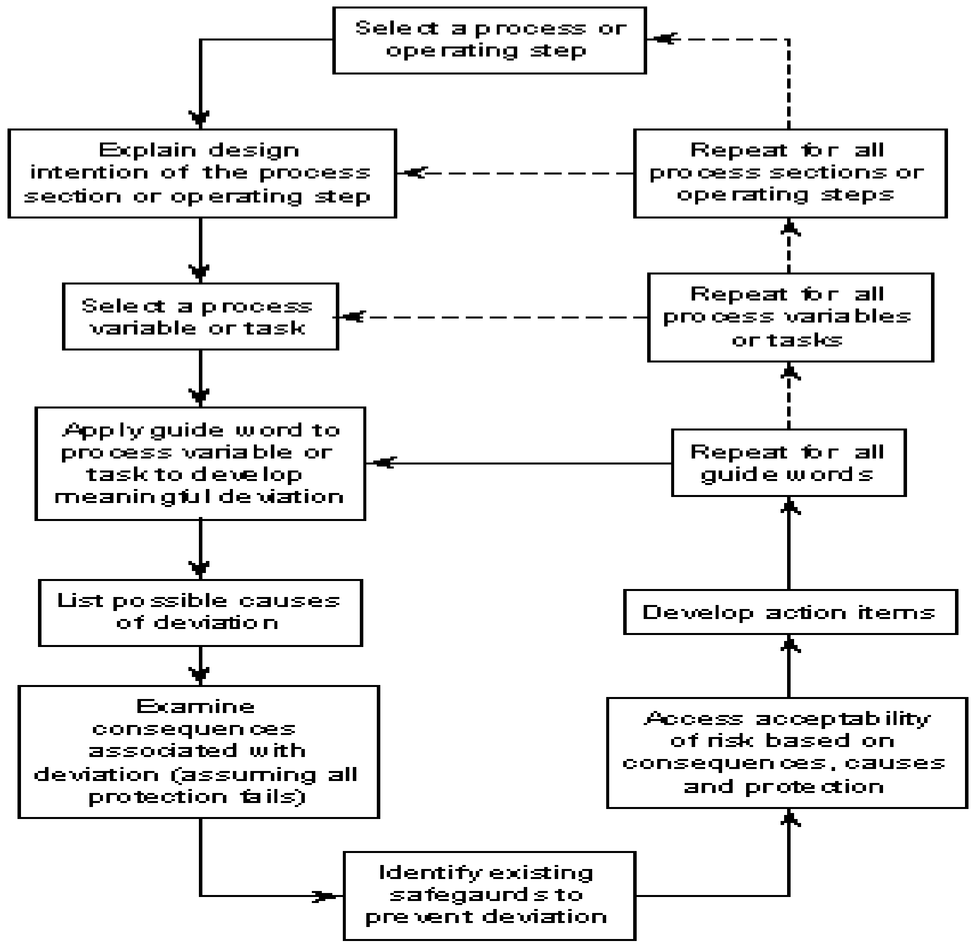


Figure 2.5 HAZOP (Hazard and operability analysis) Concept.

- The success or failure of the HazOp depends on several factors,
- The completeness and accuracy of drawings and other data used as a basis for the study,
- The technical skills and insights of the team,
- The ability of the team to use the approach as an aid to their Imagination in visualizing, deviations, causes, and consequences, and
- The ability of the team to concentrate on the more serious hazards which are identified.

The concepts presented above are put into practice in the following steps:

- Define the purpose, objectives, and scope of the study,
- Select the team,
- Prepare for the study,
- Carry out the team review, and
- Record the results.

Table 2.6 Few guide words used in HAZOP

Guide word	Standard interpretation	PES interpretation
No	No part of the intention is achieved	No data or control signal passed.
More	A quantitative increase	More data is passed than intended
Less	A quantitative decrease	Less data is passed than intended
As well as	All design intent achieved, but w additional results	Not used here because this is alrea covered by "more".
Part of	Only some of the intention is achieve	The data or control signals incomplete.
Reverse	Covers reverse flow in pipes a	The logical opposite of intention.

	reverse chemical reaction.	
Other than	A result other than the origi intention is achieved	The data or control signals complete, but incorrect.
Early	Not used	The signal arrives too early w reference to clock time.
Late	Not used	The signal arrives too late w reference to clock time.
Before	Not used	The signal arrives earlier tl intended within a sequence.
After	Not used	The signal arrives later than intend within a sequence.

2.8.3.4 PRA (probabilistic risk analysis)

Probabilistic risk assessment (PRA) (or **probabilistic safety assessment/analysis**) is a systematic and comprehensive methodology to evaluate risks associated with a complex engineered technological entity.

Risk in a PRA is defined as a feasible detrimental outcome of an activity or action.

In a PRA, risk is characterized by two quantities:

- The magnitude (severity) of the possible adverse consequence(s), and
- The likelihood (probability) of occurrence of each consequence.

Consequences are expressed numerically (e.g., the number of people potentially hurt or killed) and their likelihoods of occurrence are expressed as probabilities or frequencies (i.e., the number of occurrences or the probability of occurrence per unit time). The total risk is the sum of the products of the consequences multiplied by their probabilities. The spectrums of risks across classes of events are also of concern, and are usually controlled in licensing processes - (it would be of concern if rare but high consequence events were found to dominate the overall risk.)

Probabilistic Risk Assessment usually answers three basic questions:

- What can go wrong with the studied technological entity, or what are the initiators or initiating events (undesirable starting events) that lead to adverse consequence(s)?
- What and how severe are the potential detriments, or the adverse consequences that the technological entity may be eventually subjected to as a result of the occurrence of the initiator?
- How likely to occur are these undesirable consequences, or what are their probabilities or frequencies?

The common paradigm of Probabilistic Risk Analysis (PRA) is to analyze a system so as to express a complex hazard as a logical function (structure function) of a set of elementary events whose probabilities can be inferred, so as to derive a probability for the occurrence of the hazard. Probabilities for elementary events typically come from historical data, test data or expert opinion, everything in steps 1-3 in unexceptional. However, as we have seen, step 4 may not be possible. If there are special causes of failure, and in general there will be, then we can make no reliable prediction of future frequency. From the bayesian standpoint, the future occurrence of special causes is not encoded in our historical experience and we must not expect our inferences to be well calibrated.

The present common approach to PRA is:

1. Identify hazardous effects
2. Predict severity of hazardous effects
3. Analyze hazardous effect to enumerate initiating events
4. Estimate probabilities of initiating events
5. Estimate probability of hazardous effects
6. Assess acceptability of risk.

An alternative approach would be, following step 3, to work back from step 6, starting from an assessment of what degree of risk would be acceptable, to a specification of an acceptable probability for the hazardous event. At this stage, we now do something very similar to the old step 3. We use our historical data and expert knowledge to judge whether the specified probability is achievable. However, we do not stop there, as in a conventional analysis, because we know that such estimates are, in general, unreliable owing to likely special causes of failure and to the unpredicted normal accidents of complicated systems. Here, I propose that we can then use our conventional analysis to set up a regime of control-charting than would, during the life of the system under assessment:

- Recognize special causes of failure
- Detect unacceptably frequent failures)
- In safety critical characteristics

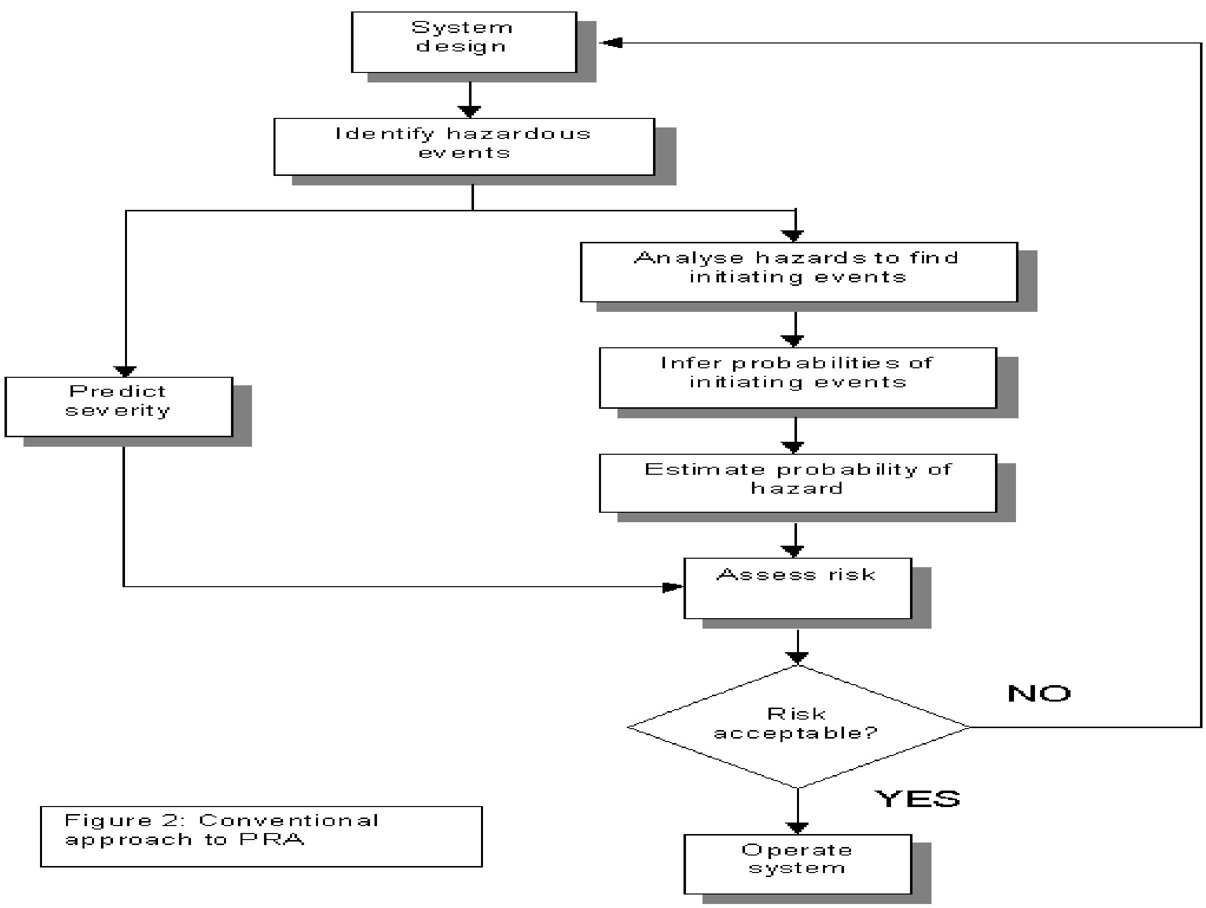


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Figure 2.7: Conventional approach to PRA

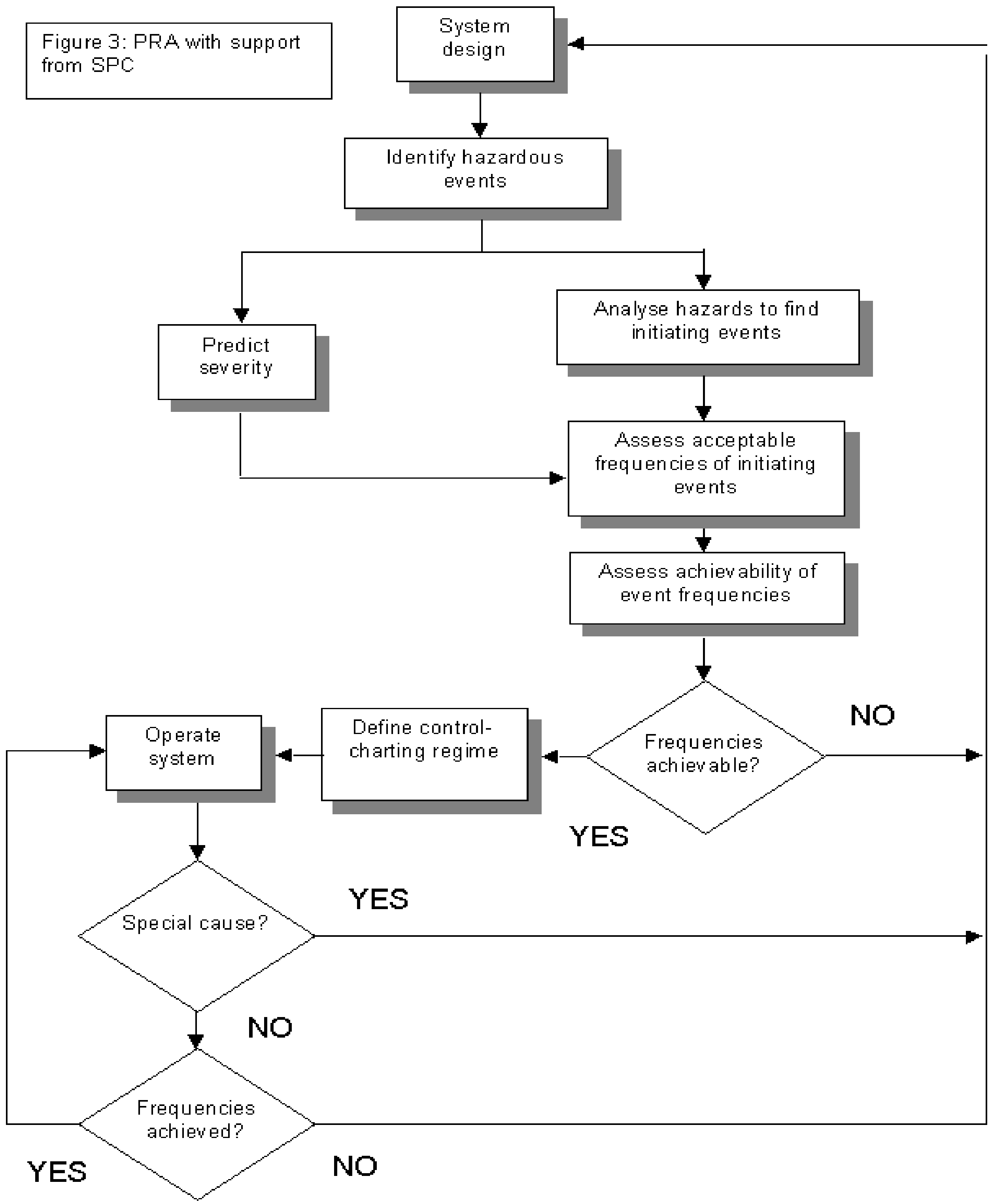


Figure 2.6 PRA with support from SPC

2.9 Basics of Environmental risk assessment

A pragmatic approach to environmental risk assessment can transform what may sometimes appear to be an extremely detailed, complex and resource-intensive process into a practical aid to decision-making. The figure provides a framework for a tiered approach to environmental risk assessment and management where the level of effort put into assessing each risk is proportionate to its priority (in relation to other risks) and its complexity (in relation to an understanding of the likely impacts). This framework also illustrates

- The importance of correctly defining the actual problem at hand,
- The need to screen and prioritise all risks before quantification,
- The need to consider all risks in the options appraisal stage, and
- The iterative nature of the process.

2.9.1 Key stages

Key stages in each tier of environmental risk assessment

1>Identifying the hazard

These guidelines define *hazard* as a property or situation that in particular circumstances could lead to harm. This may be determined by properties or circumstances and could include, for example, the release of chlorofluorocarbons (CFCs), a tidal surge along a stretch of the coast, a dry summer leading to low river flows, or the planting of a genetically modified crop. Where risk assessment is to be applied at the policy level, the hazard may be as broad as the adverse impacts of road transport on the environment, or the adverse impacts of induced climate change from the contribution of fossil fuel-derived carbon dioxide emissions.

The identification of hazards, both in the problem formulation stage, and in subsequent tiers in the process, will have an important bearing on the breadth of the overall assessment and the credibility of the final output. If these sediments were to be contaminated, they might pose an additional hazard.

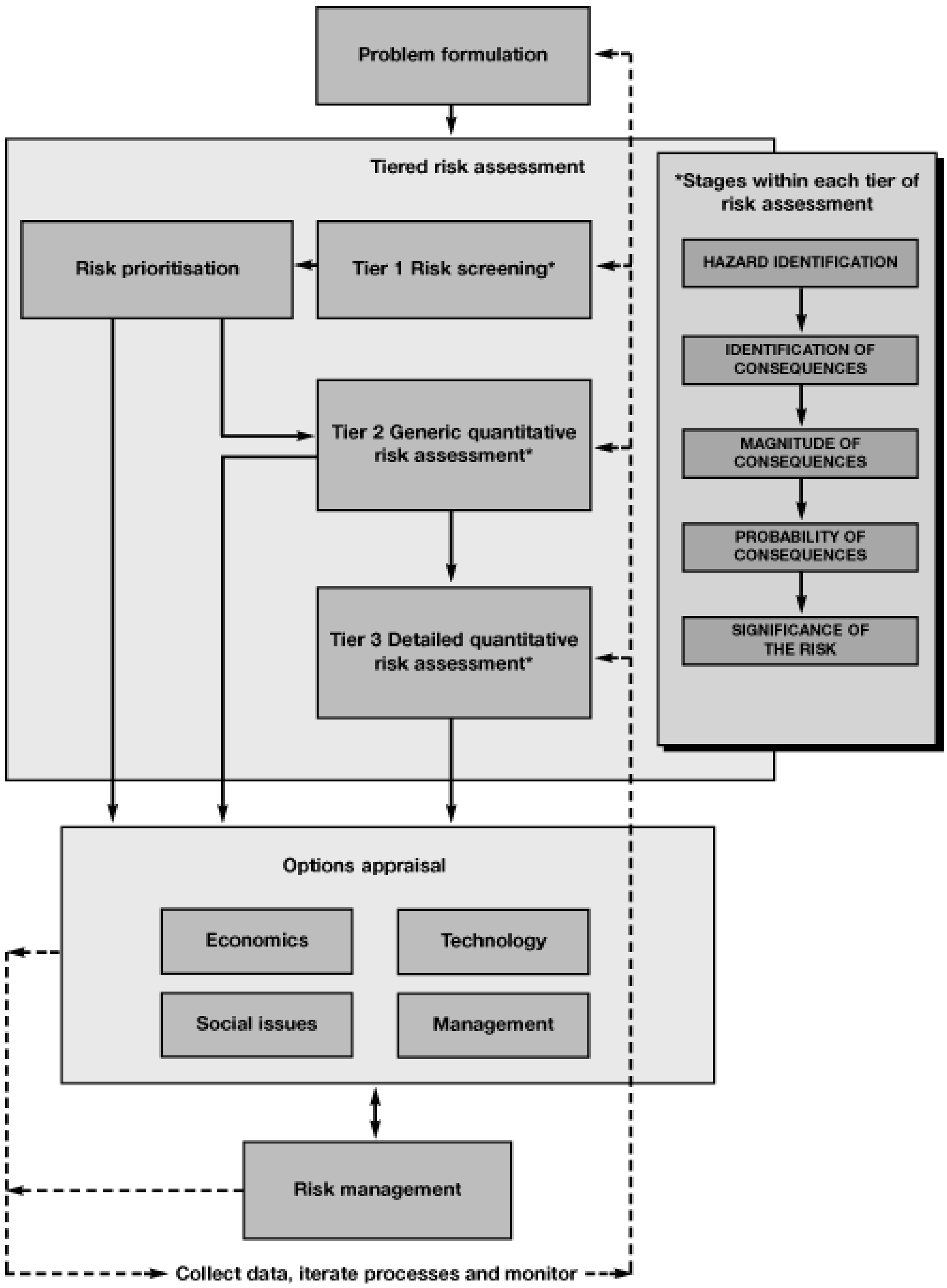


Figure 2.7 Risk Management Process

2> Identification of consequences

The potential consequences that may arise from any given hazard are inherent to that hazard. Although the full range of potential consequences must be considered at this stage, no account is taken of likely exposure and therefore likely consequences. For example, while the potential consequences of a discharge of toxic metals to a watercourse may be self-evident, a flood may have additional, non-obvious consequences such as pollution arising from an over-stretched sewerage system, or loss of habitats due to river scouring.

These examples serve to highlight why it is necessary to take a broad look at the potential environmental damage that may occur, if only to be clear why some potential consequences are rejected for further assessment.

3> Estimation of the magnitude of consequences

The consequences of a particular hazard may be actual or potential harm to human health, property or the natural environment (the issue of probability of occurrence is covered below). The magnitude of such consequences can be determined in different ways depending on whether they are being considered as part of a risk screening process, or as part of a more detailed quantification of risk. At all stages of risk assessment several key features need to be considered, as described below.

The spatial scale of the consequences

The geographical scale of harm resulting from an environmental impact will often extend considerably beyond the boundaries of the source of the hazard. Failure to consider this at an early stage may result in the scope of the risk assessment being too limited. For example, a major accident in a chemical plant is likely to have significant effects on the environment well beyond the perimeter of the site.

The temporal scale of the consequences

The duration of the harm that results may raise issues of intergenerational equity or may be so prolonged that the damage can be assumed to be permanent and the environment beyond recovery. For example, should the release of a genetically modified crop result in extensive cross-breeding with adjacent indigenous flora, any harmful environmental impacts could extend far into the future.

The time to onset of the consequences

A further factor to consider is how quickly harmful effects might be seen. Standard economic techniques tend to discount impacts that will happen in the future but sustainable development emphasises the need to protect the interests of future generations. Risk assessment and management must therefore pay as much attention to long-term problems as to the more immediate risks. For example, the spillage of a solvent on porous ground may not result in an impact on the underlying aquifer for decades. Once realised, however, the duration of the harm is likely to be of the order of decades and will compromise the value of that aquifer as a source of water for future generations.

The ability to forecast the time-scale and magnitude of the environmental impact through robust and long-term modelling is therefore valuable, particularly at the quantifiable end of the risk spectrum.

Stage 4: Estimation of the probability of the consequences

All stages to this point have assumed that realisation of the hazard will lead to environmental harm. However, the probability of the consequences occurring must also be taken into account. This has three components:

- The probability of the hazard occurring
- The probability of the receptors being exposed to the hazard
- The probability of harm resulting from exposure to the hazard

The probability of the hazard occurring

Depending on the circumstances, assigning probabilities may be quite straightforward or may require some sophistication in approach. For example, at a screening level, it might be as simple as stating, on the basis of experience, that on a scale of 1 (low) to 5 (high) a pin-hole leak in a particular pipe in a chemical plant has a probability of, say, 4. Floods can be categorised by their return period (eg one in a hundred years) based on historical records. On the other hand, there will be situations in which it is necessary to assign a probability distribution to the likelihood of the event occurring - for example, that a non-genetically modified crop will be widely pollinated by a genetically modified crop. In many instances this information can be obtained from monitoring data, or based on 'worst-case' or 'reasonable worst-case' scenario estimates.

The probability of the receptors being exposed to the hazard

It is important to establish, at an early stage in the process, whether or not a pathway exists between the hazard and the receptor. If it can be shown that no actual or potential connection exists, then the risk requires no further attention. For example, soil contamination will not pose a risk to farm animals if the land is not used for agricultural purposes. But care is needed not to overlook less obvious pathways, or changes in future circumstances.

Having established one or more pathways, the degree of exposure via those pathways should be quantified. A range of factors will affect the probability and degree of exposure. For example, the exposure of a receptor to an atmospheric emission of sulphur dioxide will depend on the direction and strength of the prevailing wind at the time of release. The impact of a coastal flood in a tourist area may be dictated by the time of the year at which the flood occurs; the loss of property may be greater in summer when caravan parks are occupied than during the winter season when occupancy is likely to be low.

The probability of harm resulting from exposure to the hazard

Even following exposure, the likelihood of harm resulting is probabilistic and will depend on the likely susceptibility of an individual receptor to the hazard and the amount and duration of exposure. This is often simplified in terms of a dose-response relationship, which directly relates exposure to the magnitude of harm for certain receptor types. Such relationships frequently embody 'safety' or uncertainty factors to account for the extrapolation of data from experimental or generalised studies. In flood damage assessment, for example, standard depth-damage curves are used to relate the depth of flood waters to the amount of damage sustained by a building or its contents, again according to the duration of exposure to the flood waters. These relationships simplify the probabilistic nature of harm, because for any exposure, the likelihood of harm at a certain magnitude will be dependent on many individual factors. Few risk assessments allow for this level of sophistication, and the magnitude of harm is usually taken as a direct result of exposure.

Stage 5: Evaluating the significance of a risk

This stage is often referred to as risk characterization, although this terminology tends to hide the true goal of the activities involved. Having determined the probability and magnitude of the consequences that may arise as a result of the hazard, it is important to place them in some sort of context. It is at this point, therefore, that some value judgments are made, either through reference to some pre-existing measure, such as a toxicological threshold, environmental quality standard or flood defense standard, or by reference to social, ethical, or political standards. In some circumstances, a formalized quantitative approach to determining significance may be possible, for example the tolerability of risk (TOR) framework developed by the Health and Safety Executive. In other instances, the risks of various options might be compared against one another.

Table 2.7 Hazards associated with environment

BROAD CLOSURE RISK	SUB ISSUE	SPECIFIC EVENT (OPTIONS)
Water	Surface waters	Sedimentation
		Effluent
		Drainage
		Acid Mine Drainage (AMD)/heavy metals
		Salinity
	Ground waters	Contamination (ARD, NMD and processing chemicals)
		Drawdown
	Downstream usage	Agriculture
		Drinking
		Aquatic Ecosystem
Air	Gas	Greenhouse gas emissions
		Other emissions (eg SO^2)
	Dust	Tailings
		Stockpiles
		Rehabilitated areas
Land systems	Aesthetic values	Close to population centre or main roads
		Remote
	Infrastructure	Buildings, equipment, camps
		Roads
		Stockpiles, dumps, dams, sumps
		Borrow pits
	Soils	Contamination
		Topsoil availability/suitability
		Erosion potential
	Reshaping/earthworks	
	Flora reestablishment	Simple
		Complex
		Rare/significant
	Fauna reestablishment	Terrestrial
		Avian

		Aquatic
	Voids	Open
		Backfill (using waste rock)
	Subsidence	
	Exploration	
	Management/monitoring	
Wastes	Dumps	Reshaping
		Covers
		AMD
		Topography
		Seismicity
		Climate
	Tailings	Reshaping
		Covers
		AMD
		Toxicity
		Stability
		Landbased
		Riverine
		Submarine
	Hazardous materials	Chemicals including cyanide
		Fuels, lubricants
	Other	Sanitation
		Tyres, machinery etc
		Garbage
Heritage	Indigenous	
	Non-indigenous	

2.9.2 Fire Risk Assessment

During a risk assessment, hazards are evaluated in terms of the likelihood that a problem may occur and the damage it might cause. Mine fire preparedness requires consideration of all possible fires that could occur. However, at a given mine some fires are more likely than others and some would result in greater damage than would others. Conducting a risk analysis identifies these differences. The results can be used to target resources at the types of fires that are most likely and/or are most destructive. Hazards that are very likely to result in fires that would do considerable damage to people and property should be targeted first for remediation and/or effective response if remediation isn't possible. Potential fires that are less likely or that would have less severe consequences are identified for attention later, after the more serious situations have been addressed.

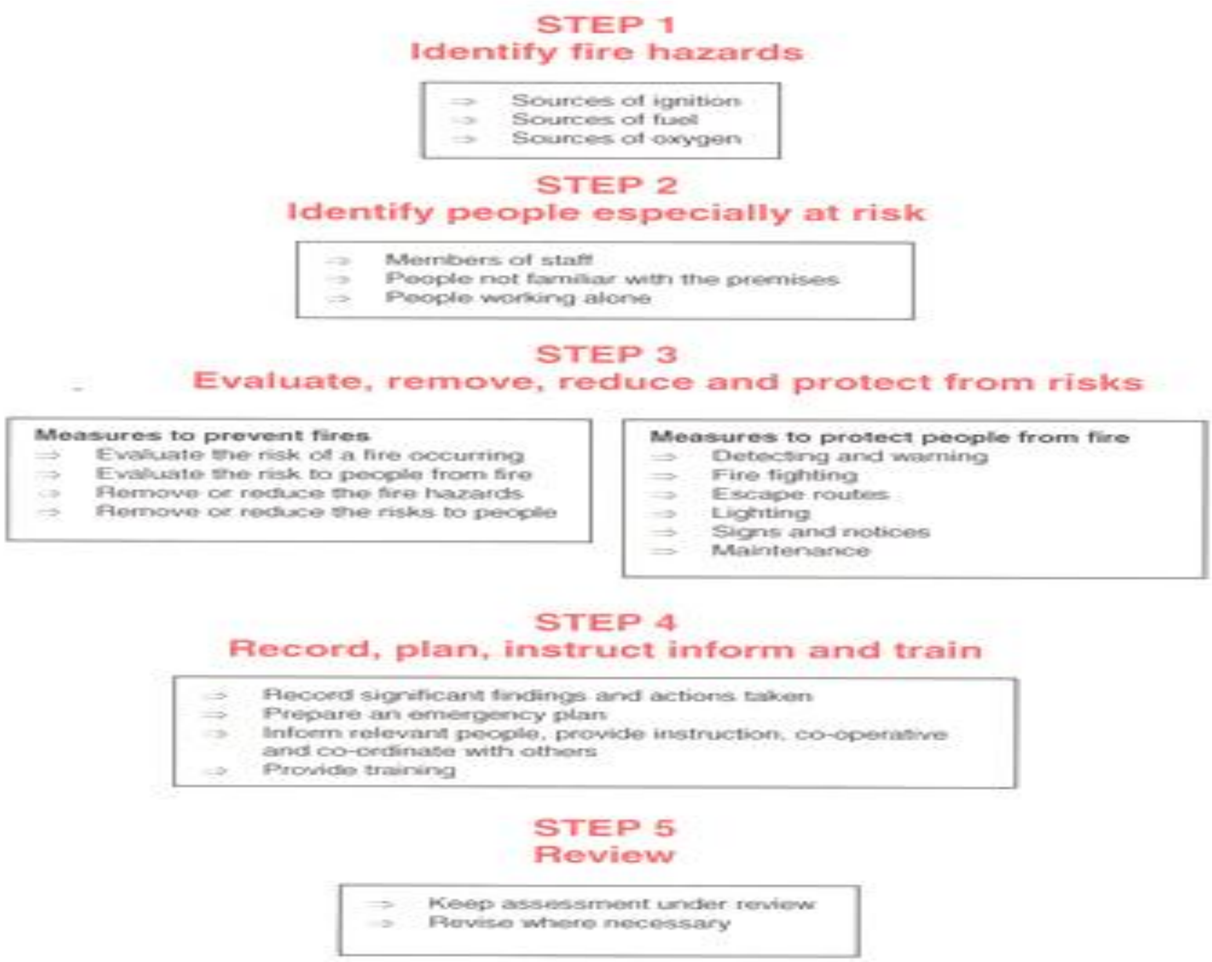


Fig 2.8 Fire Risk Assessment

2.10 IMPACTS OF MINE CLOSURE

Table 2.8 Closure risk assessment matrix

Probability	10 (certain)	9	8	7	6	5	4	3	2	1 (rare)
Consequence										
10 (catastrophic)	100	90	80	70	60	50	40	30	20	10
9	90	81	72	63	54	45	36	27	18	9
8	80	72	64	56	48	40	32	24	16	8
7	70	63	56	49	42	35	28	21	14	7
6	60	54	48	42	36	30	24	18	12	6
5	50	45	40	35	30	25	20	15	10	5
4	40	36	32	28	24	20	16	12	8	4
3	30	27	24	21	18	15	12	9	6	3
2	20	18	16	14	12	10	8	6	4	2
1 (insignificant)	10	9	8	7	6	5	4	3	2	1

Production plans and closure horizons will however be influenced by myriad factors at both the local and global levels, and this makes it extremely difficult to predict when mine closure will occur and what the socioeconomic conditions will be like at the time of closure. However, it is clear that Chambishi is currently very dependent on the mining sector for its economic survival and that other sectors of the economy are largely undeveloped and that as long as this situation prevails, any reduction in, or cessation of, mining activity in Chambishi will have a significant and detrimental socioeconomic impact. Past experience suggests that to effectively militate against the negative impacts of mine closure close cooperation between all relevant stakeholders, effective long-term planning and the provision of sufficient financial and human resources are critical. Precise closure impacts are difficult to predict, as it is not known what the socioeconomic environment will be like when the mine closes. However, potential impacts will include:

- Loss of mining jobs and consequent loss of income for individuals and dependents,
- Loss of benefits to mine employees,
- Closure or shrinkage of local business, both formal and informal, those are reliant directly on the mine or on mine employees for their business,
- Loss of jobs in sectors serving the mine,
- Increased unemployment due to the lack of employment opportunities in other sectors,
- Increase in informal business and land-based livelihood activities,
- Increased poverty if ex mine workers, and others deriving an income from the mine, do not find alternative livelihoods to provide equivalent incomes,
- Growth in informal settlements,
- Deterioration in condition of housing stock,
- Disruption to or deterioration in health care facilities and services currently run by NFCA if there is insufficient planning for hand-over to suitable authorities prior to mine closure,
- Out migration of skilled professionals, and
- Disruptions to water supply and sanitation services if there is insufficient planning of water supply management prior to mine closure.

Tailings dumps from past mining activities around Johannesburg in South Africa, which are a source of dust affecting the health of neighboring populations. In some cases the responsibility for the rehabilitation of the dumps can be attributed, but economic conditions have prevented rehabilitation.

The major impacts of abandoned mine sites are acid mine drainage, loss of productive land, visual effects, surface and groundwater pollution, soil contamination, siltation, contamination of aquatic sediments and fauna, air pollution from dust, risks posed by abandoned shafts and pits, and landslides due to collapse of waste and tailings dumps.

Impacts that change conditions affecting these objectives are often broadly discussed as the 'impacts' or the environmental impacts of a site or a closure plan. It is convenient to consider potential impacts in four groupings:

1. **Physical stability** - Buildings, structures, workings, pit slopes, underground openings etc. must be stable and not move so as to eliminate any hazard to the public health and safety or material erosion to the terrestrial or aquatic receiving environment at concentrations that are harmful. Engineered structures must not deteriorate and fail.
2. **Geochemical stability** - Minerals, metals and 'other' contaminants must be stable, that is, must not leach and/or migrate into the receiving environment at concentrations that are harmful. Weathering oxidation and leaching processes must not transport contaminants, in excessive concentrations, into the environment. Surface waters and groundwater must be protected against adverse environmental impacts resulting from mining and processing activities.
3. **Land use** - The closed mine site should be rehabilitated to pre-mining conditions or conditions that are compatible with the surrounding lands or achieves an agreed alternative productive land use. Generally the former requires the land to be aesthetically similar to the surroundings and capable of supporting a self-sustaining ecosystem typical of the area.
4. **Sustainable development** - Elements of mine development that contribute to (impact) the sustainability of social and economic benefit, post mining, should be maintained and transferred to succeeding custodians.

Clearly the assessment of these types of impacts and closure requirements must address components of the site as well as the region and must select measures and allocate resources to address the major issues of impact. In order to minimize the various impacts, risks and liabilities, it is necessary to anticipate, as early in the process as possible, potential future liabilities and risks, and to plan for their elimination or minimization. In many areas, much of the liability or risk is associated with the uncertainty of the requirements for closure and rehabilitation from the succeeding custodian (be it a government agency, community organization or corporate entity). Early identification of the succeeding custodian and their involvement in the development of the closure plan enables the closure requirements to be established and agreed and considered in the closure plan development.

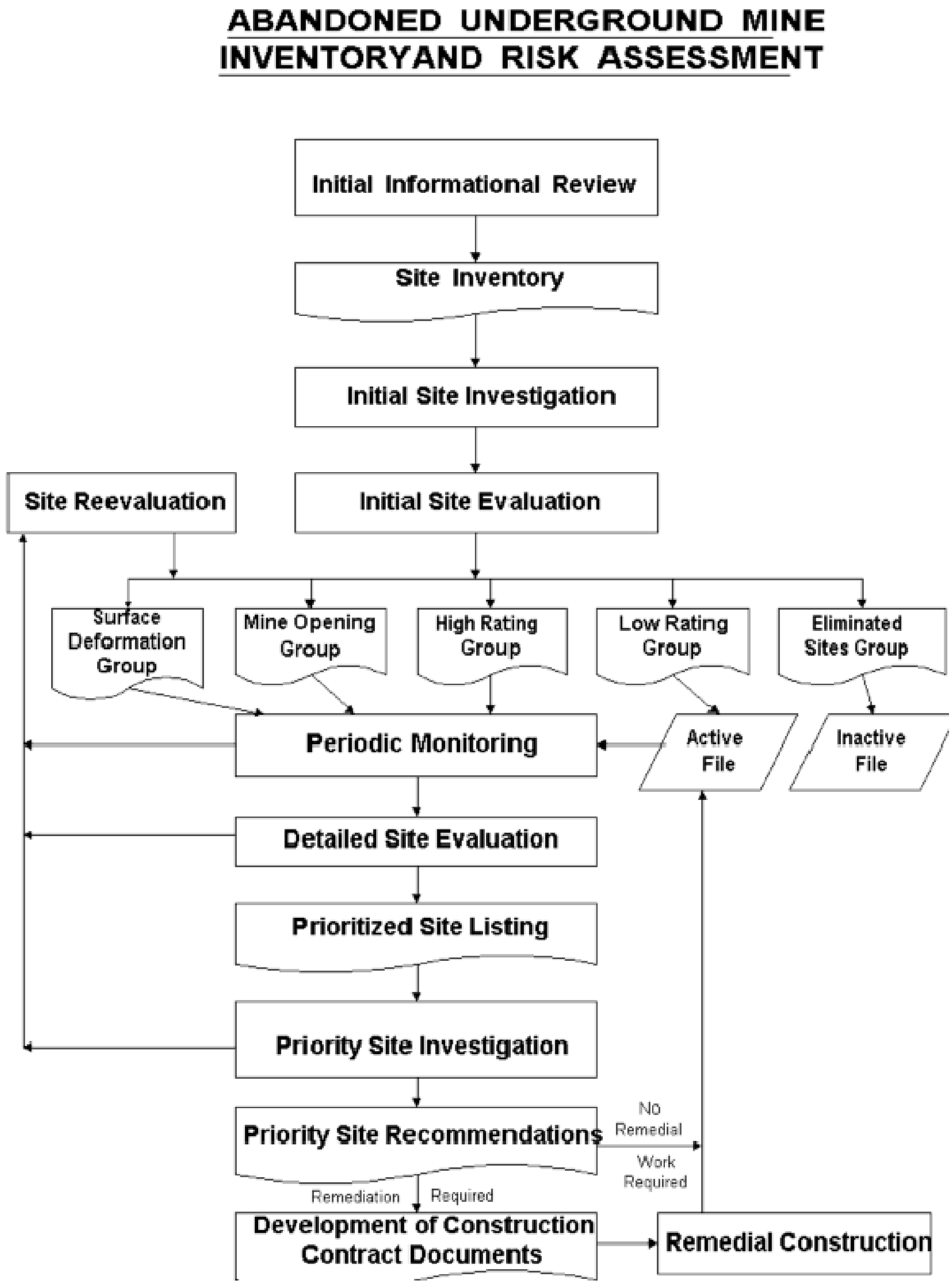


Fig 2.9: Abandoned underground mine inventory and risk assessment

This allows the mining company to determine, and provide for, the requirements of the succeeding custodians, gain their support for the closure plan and minimize the risks and liabilities that may derive from succeeding custodian rejection or objection to the closure measures at the time of mine closure.

Landscape degradation

Alpine environment is extremely sensitive regarding the interference in the natural ecosystem. Open pits, mining dumps, and tailing dams are a severe degradation of the environment. Due to the specific climatic and topographic conditions in an Alpine environment nature's self-healing capabilities are considerably reduced. As in this area the economy relies on tourism to a considerable extent, human support is needed to minimize the negative effects of mining activities and to speed up the process of mining site re-naturation.

Landslides - dump slope stability

Not stabilized mining dumps are potential thread because of the possibility of dump slides, endangering people, infrastructure, and the environment. Dump stability depends on many factors, e.g. type of material, grain or block size, slope angle, thickness, water content, and type of cover (uncovered material, different types of vegetation). Mining dumps can be stabilized by means of landscaping and reforestation, thus regulating water balance within the tailings.

Contamination

Because of the relatively pure carbonatic iron ore mined at Erzberg, direct contamination by toxic material is not a major problem in this case. However in general mining dumps are a potential thread to the environment because of leaching of toxic elements by precipitation, or dust blow-out from the tailings. These effects can be reduced by targeted remediation activities, reforestation being an effective method to inhibit excessive percolation of dumps by precipitation. Therefore methods for environmental monitoring developed at Erzberg test site will be applicable also to mining sites with serious contamination problems.

Physical Impact

Beyond the potential for pollutant impacts on human and aquatic life, physical impacts are associated with the sedimentation, including the filling of deep pools resulting in the loss of habitat for fish and an increase in temperature. The sedimentation an also result in the filling of downstream reservoirs reducing the capacity for both flood control and power generation. The sedimentation can also cause the channel to widen and become shallower, which may increase the frequency of over bank flow.

Impact of Uranium Mining

In many respects uranium mining is much the same as any other mining. Projects must have environmental approvals prior to commencing, and must comply with all environmental, safety and occupational health conditions applicable. Increasingly, these are governed by international standards, with external audits. Once approved, open pits or shafts and drives are dug, waste rock and overburden is placed in engineered dumps. Tailings from the ore processing must be placed in engineered dams or underground. Finally the whole site must be rehabilitated at the end of the project. Meanwhile air and water pollution must be avoided. These processes are common to all metalliferous mining, and are well recognized and understood.

Figure 2.10 Abandoned uranium mine

2.10.1 Acid Mine Drainage (AMD):

Acid mine drainage, results when the mineral pyrite (FeS_2) is exposed to air and water, resulting in the formation of sulfuric acid and iron hydroxide For chemists, the equation for AMD formation is:

$FeS_2 + 3.75\ O_2 + 3.5\ H_2O$ Û $Fe(OH)_3 + 2\ H_2SO_4$

Pyrite is commonly present in coal seams and in the rock layers overlying coal seams. AMD formation occurs during surface mining when the overlying rocks are broken and removed to get at the coal. It can also occur in deep mines which allow the entry of oxygen to pyrite-bearing coal seams. One leading method of reclamation that has been used in other parts of the world, and which could also be used in the Amazon, is the creation of special artificial wetlands. These wetlands can survive in acidic conditions, and they support microbes that can actually convert the acid into less toxic compounds.

Water that is discharged from mining or mine-related operations which contains high levels of dissolved iron and aluminum sulfates in conjunction with pH values less than 4.5 (acidic). It is produced when oxygen dissolved in water reacts with pyritic (iron sulfide) materials found in association with most coal deposits. Acid mine drainage (AMD) degrades the water quality of streams and water supplies, often to the point of eliminating all biological activity within the stream contaminated with AMD.

Treatment of AMD could also involve chemical neutralization of the acidity, followed by precipitation of iron and other suspended solids. Such treatment systems include:

1. Equipment for feeding the neutralizing agent to the acid mine drainage,
2. Means for mixing the two streams (acid mine drainage and neutralizing agent),
3. Procedures for ensuring iron oxidation, and
4. Settling ponds for removing iron, manganese, and other co-precipitates.

Many factors dictate the level of sophistication that the treatment system must have to ensure that effluent standards will be met. These factors include: the quantity of AMD to be treated, the chemical characteristics of the AMD, climate, terrain, sludge characteristics, and projected life of the mining plant. The chemicals which are usually used for AMD treatment include limestone, hydrated lime, soda ash, caustic soda, and ammonia.

2.7 RISK MANAGEMENT:

2.7.1 Safety Management Systems

A Safety Management System (SMS) consists of comprehensive sets of policies, procedures and practices designed to ensure that barriers to unwanted incidents are in place, in use and are effective. An integrated SMS focuses on both the traditional OHS area and on management of engineering safety. The SMS tends to integrate all aspects of safety into the ongoing activities of everyone involved in the operations—from the operator to the chief executive officer. The responsibility for safety is both individual and collective.

Characteristics of Safety Management Systems

The major characteristics of SMS are:

• It is the principal vehicle for day to day management of all aspects of safety in the operations.

• Its focus is not only on personnel safety, but also ensuring operational integrity and minimizing business interruptions, even if no one was injured.

• It outlines a set of procedures for everyone to follow (depending on their roles and responsibilities, a select set of procedures may apply to each operating group), is system-dependent and NOT individual-dependent.

• It contains a list of safety critical equipment, and how these are maintained to required operational integrity through safety critical activities. The activities, procedures, schedules and responsibilities are defined.

• It lists a set of performance indicators to monitor the integrity of the safety critical activities being undertaken correctly and according to schedule.

• It outlines an auditing and feedback regime for management control of hazards. It should be recognized that without a formal well-defined SMS, followed by adequate training, implementation and monitoring, major hazards are impossible to manage of a PE system.

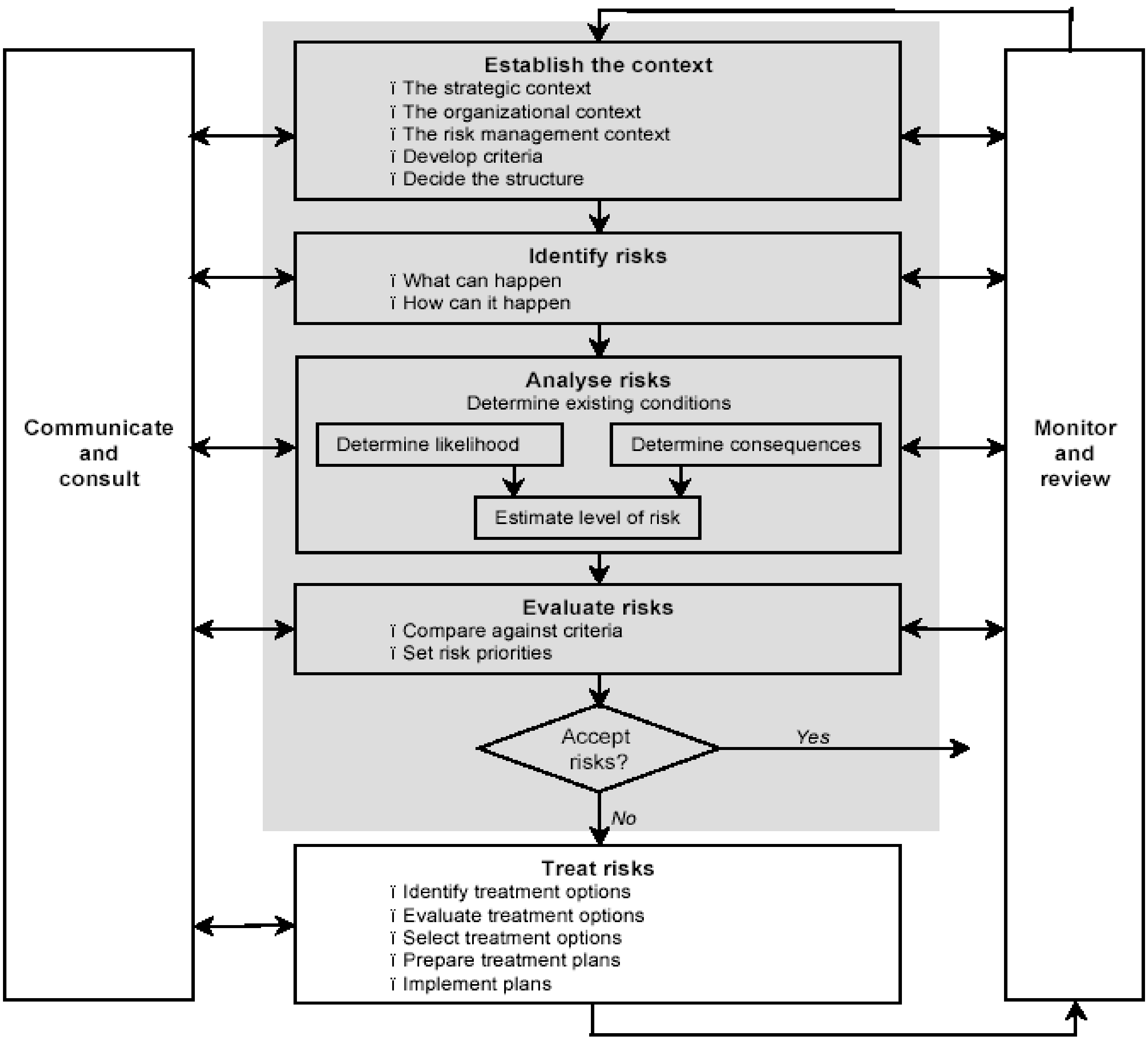


Fig.2.11 Safety Management System

CHAPTER 3

DEVELOPMENT OF COMPUTER PROGRAMS AND CASE STUDIES FOR SAFETY AND ENVIRONMENTAL RISK ASSESSMENT IN MINES

Computer modeling in Risk Assessment is a relatively new process. Risk Assessment for mines is even scarce and rare to be found in application using computers. In today's world we have the availability of good software's and fast machines. It is possible to quantify and compile many of the nuances of Risk hazards in mines, the only problem being that no suitable methodology exists. Even in professional Disaster management institutes, Risk Assessment and Disaster Management Plans for mine workings are not undertaken, so the need for it has to be emphasized.

3.1 FAULT TREE+ 11.0

FaultTree+11.0 analysis program for Microsoft Windows enables us to analyse the availability and reliability of both complex and simple systems and is easy and intuitive to use. Fault tree provides an integrated environment for performing fault tree analysis, event tree analysis and Markov analysis. The program is rich in features and can model a wide range of scenarios. The Fault Tree+ 11.0 program is a powerful systems reliability analysis tool that allows fault and event tree analyses to be performed in an integrated environment. Customized Markov models may also be linked to events in the fault or event tree diagram. The program may also be used to analyze fault trees, event trees and Markov models independently.

Fault tree software was studied and used for drawing of Fault Tree and Event Trees. It was used to construct a fault tree for fire risk assessment (Fig.3.1).

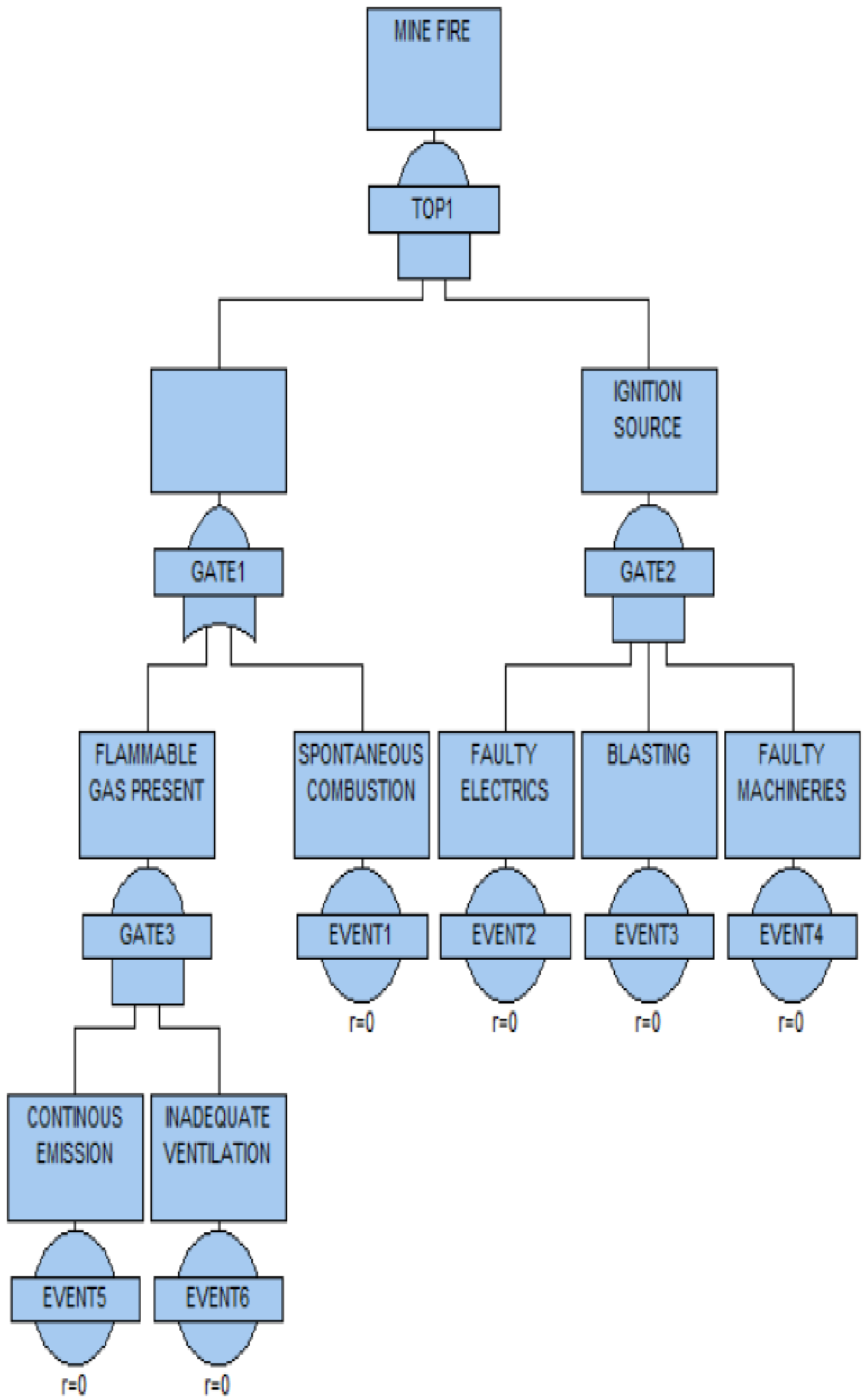


Fig.3.1: Fault Tree for Mine Fire Modeling-1

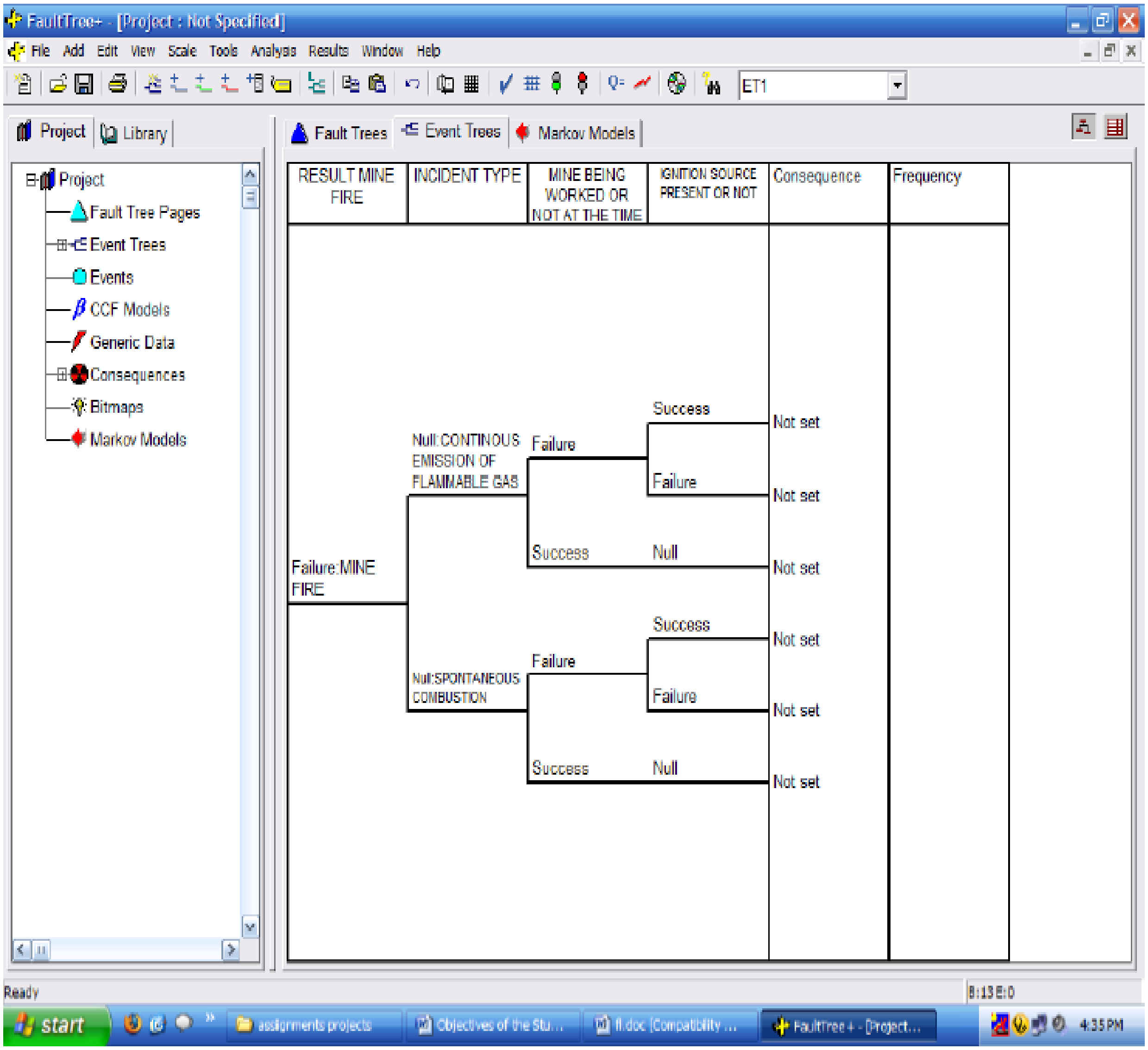


Fig 3.2 Event Tree Using for Mine Fire Modeling-2

3.2 PROGRAMMING MODEL FOR SPONTANEOUS FIRE RISK POTENTIAL IN UNDERGROUND MINES

Problem of fire due to spontaneous hating in underground panels is of great concern to mine personnel. Apart from the intrinsic characteristics of coal, the environment originated from the mining operations is also responsible for the fire .There are several models developed in different countries for estimation of fire risk potential of mine panels. In this project, computer program was written in C++ for estimation of spontaneous fire risk potential of underground Bord and Pillar workings. The program was developed based on the approach suggested by Roy(2006).

Assign each of the major mine parameters that can influence underground panel fire, an appropriate fire risk value and then to estimate overall fire risk rating of the panel.
The no of parameters was divided under 3 groups.

1) **Panel specific group**

-State of extraction
- Nature of extraction
-Existence of coal in roof and crushed pillars
-Frequency of roof fall
-Size of panel

2) **Environment group of parameters**

-geological disturbances, quality of overburden, existence of subsidence, improper ventilation, leakage of air through isolation stoppings, incubation period of seam,etc

3) **Coal and seam characteristicsgroup of parameters**

-Crossing point temperature
-Wetness of mines
-Existence of pyrite band
-Particle size distribution
Flowchart for the same model is shown below:-

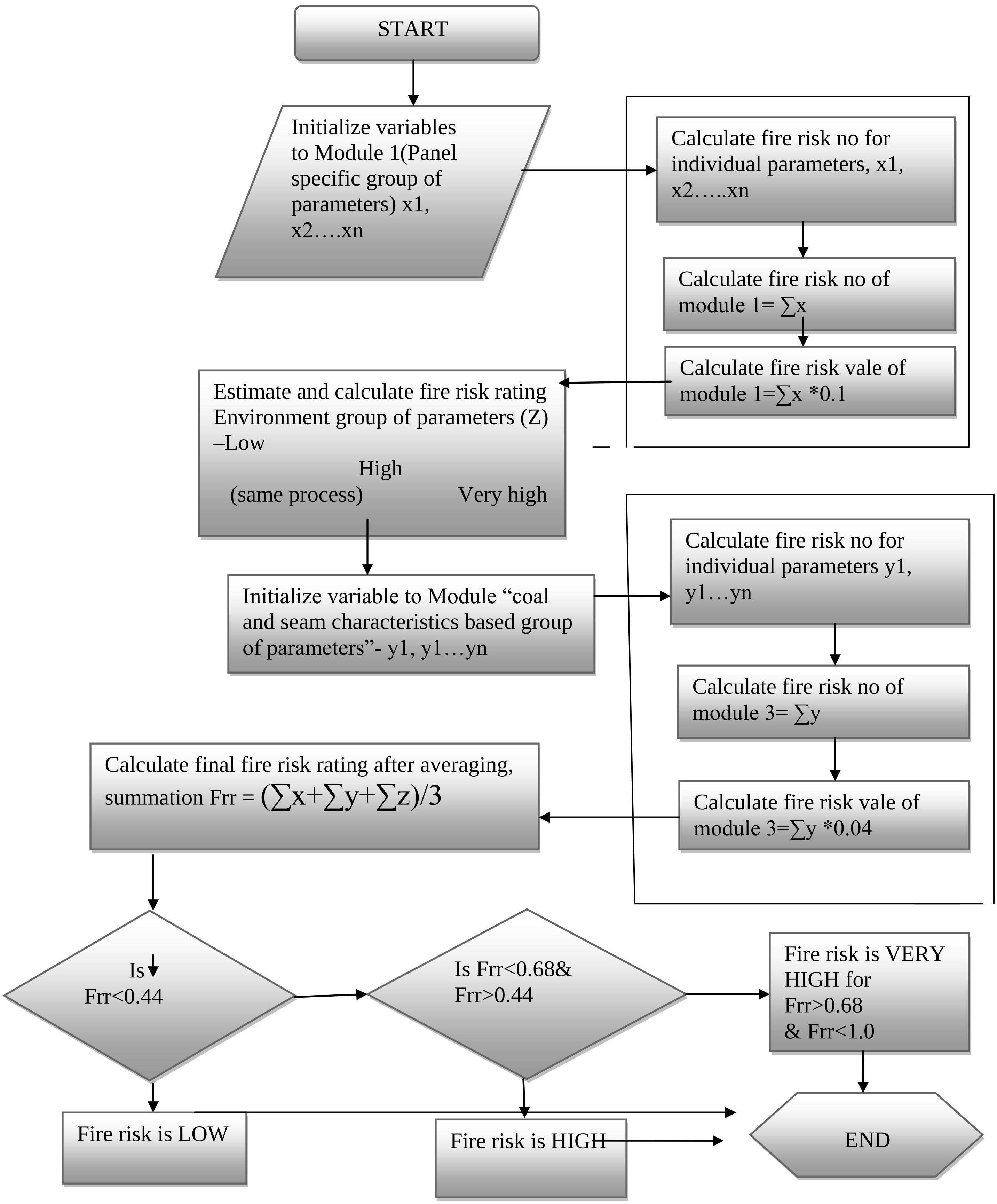


Figure 3.3 Flowchart for fire risk potential for underground mines

:

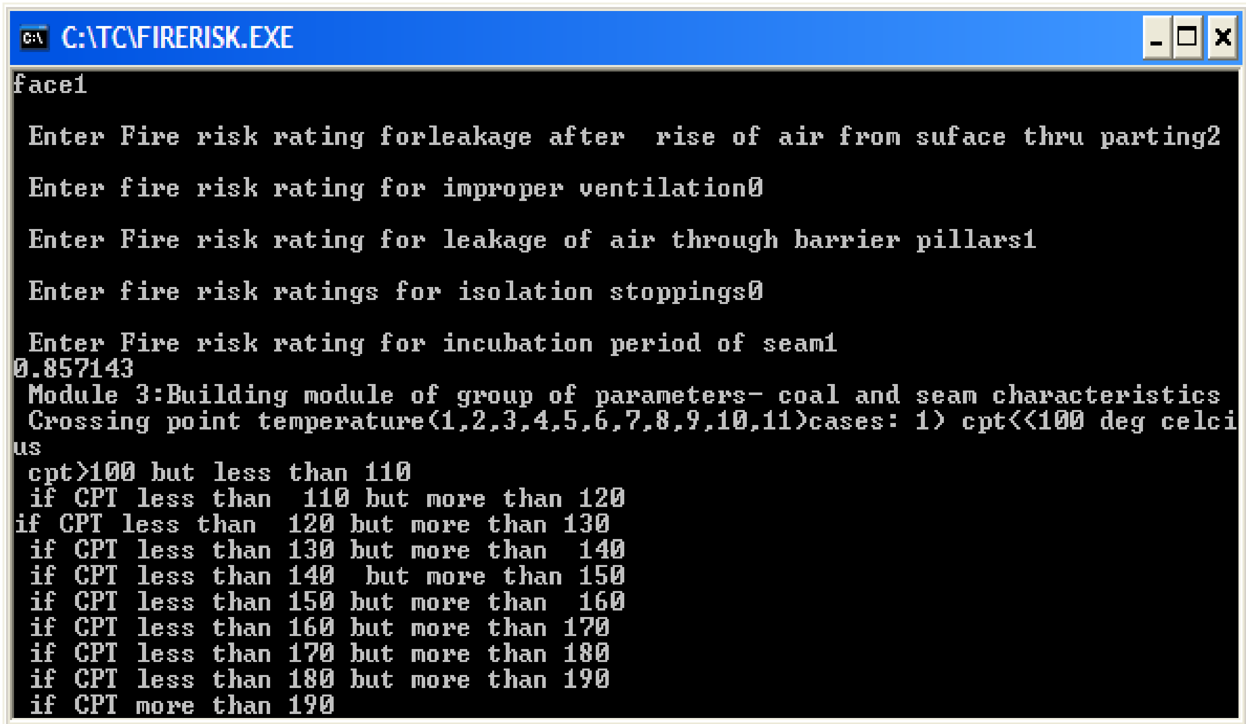
3.2.1OUTPUT

C:\TC\FIRERISK.EXE

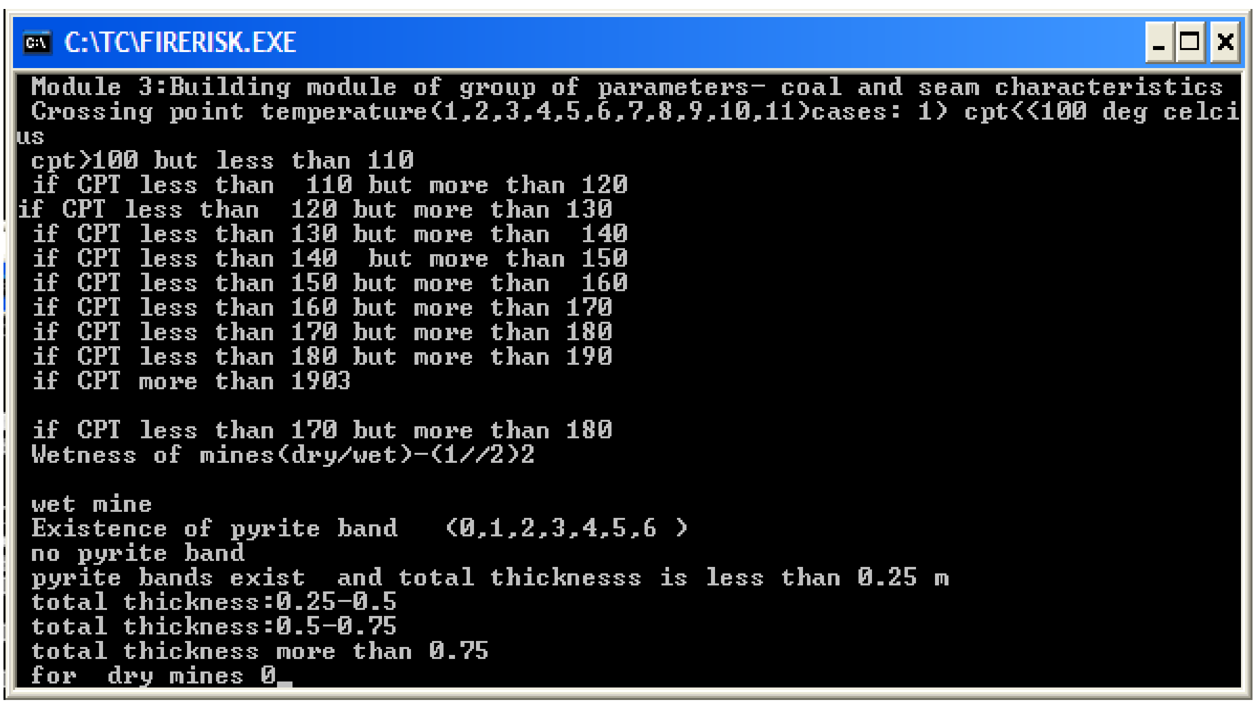
```
 state of extraction (assuming tere is no coal in roof)partially depillared/enti
rely depillared(2/3)3

  Entirely  depillared
 Nature of extraction:Conditions -extraction in single lift(0)/extraction in mor
e than one(1)1

 extraction in more than one
 Existence of coal in roof completely dipllared:conditions-less than1.5m coal in
 roof/more than it- (0)/(1)1

 1.5m or above in roof
 Frequency of roof fall(when coal is 1.5 m or more:conditions Heavy roof fall/re
st of the cases-(1)/(0))0

 rest of the cases
 Existence  of crushed or crakced pillars(0 if pillar exists and 1 if it doesnt)
1

 if it doesnt
  size of panel upto 30 pillars(0),31 to 50 pillars(1),above 50 pillars(2)2
```

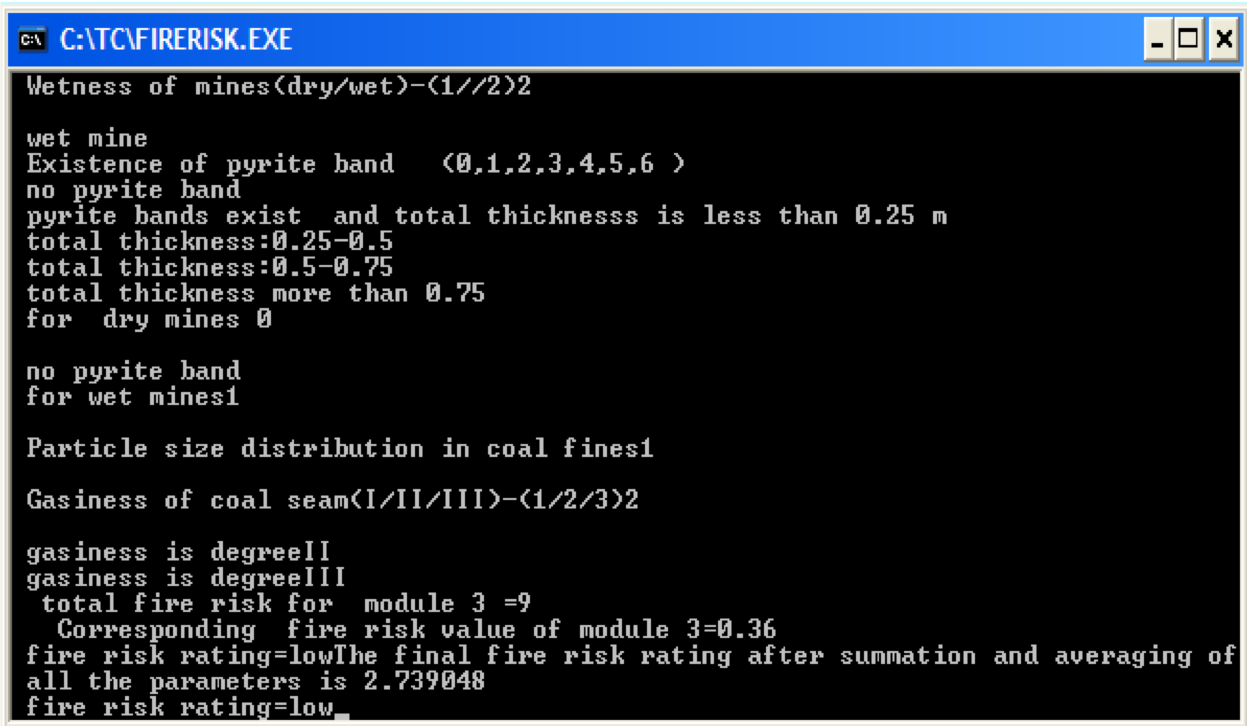
C:\TC\FIRERISK.EXE

```
 if it doesnt
  size of panel upto 30 pillars(0),31 to 50 pillars(1),above 50 pillars(2)2

   above 50 pillars
 Heat dissipation by conduction:Conditions- If coal exits neither in roof nor in
 floor(0)/coal exists either in roof or in floor/  when coal exists in both(1)1

  when coal exits in both
 TOtal fire risk number of module 19
 corresponding fire risk module 10.9
 for FIRE risk rating module 1 (group of parameters panel specifics)
 Fire risk is very high
   Module 2   =Environment group of parameters
 Enter fire risk rating for geological disturbances1

 Enter fire risk rating for existence of disturbance /cracks and fissures on sur
face1

 Enter Fire risk rating forleakage after  rise of air from suface thru parting2

 Enter fire risk rating for improper ventilation0

 Enter Fire risk rating for leakage of air through barrier pillars1

 Enter fire risk ratings for isolation stoppings
```



Fire risks for individual modules are being calculated out, and the risk is rated from low to High.





Finally, the fire risk value is calculated and it’s rated **low**.

3.3 The Closure Risk Factor (C_{RF})

It is simply a qualitative and quantitative measure that captures the various significant risk components of mine closure. These components can be broadly divided into environmental risks (R_E), safety and health risks (R_{SH}), community and social risks (R_C), final land use risks (R_{LU}), legal and financial risks (R_{LF}) and technical risks (R_T). The Closure Risk Factor is the sum of these individual risks and the relationship can be expressed by the following linear equation:

$$C_{RF}=\sum(R_E+R_{SH}+R_C+R_{LU}+R_{LF}+R_T)$$

The C_{RF} allows the closure risks at each mine site to be broken down into as many individual components

The Closure Risk Model was developed as a new tool to aid decision makers in the complex area of mine closure. It uses a simple analytical technique that allows the decision maker to simplify what is often a complex mine closure process into more easily managed sub components. This systematic approach ensures that critical factors in the closure process are not overlooked.

The approach adopted here was first developed by Prof David Lawrence(2002) where he breaks down the issues into as much detail as required. He listed and assigned a weighting to each of the major issues. Clearly, this will be a site-specific process. For the purposes of the model, it is assumed that a neutral weighting of 1.0 should be assigned to those primary issues considered to be of minor importance or have minimal risks, with a weighting of 2.0 for the extreme risks.

For example, at a particular mine it may be determined by the analytical team that the major risk ratings are:

- Environment = 1.8
- Community = 1.7
- Safety = 1.4
- Final land use = 1.5
- Legal/financial = 1.2
- Technical = 1.0.

The second step is to list and weight the significance of the secondary issues. For example, if we consider the environment, it may be that water is the most significant followed by surface, wastes and air, at 1.5, 1.3, 1.2 and 1.1 respectively.

The final step is to identify and rate the specific or lower order risks and for this prototype model, the issues have been rated out of a maximum of 10. For example, the water issues may be;

- AMD potential = 10
- potential for cyanide pollution = 6

The surface issues might be:

- erosion (highly dispersible soils) = 8
- aesthetics (visibility to public) = 9
- threat to endangered bird species = 7

Therefore the risk factor for the environmental component is:

R_E = weighting <u>environment</u> x [weighting <u>water</u> x (specific <u>water</u> issues scores) + weighting <u>surface</u> x (specific <u>surface</u> issues scores) + weighting <u>wastes</u> x (specific <u>wastes</u> issues scores) + weighting <u>air</u> x (specific <u>air</u> issues scores)].

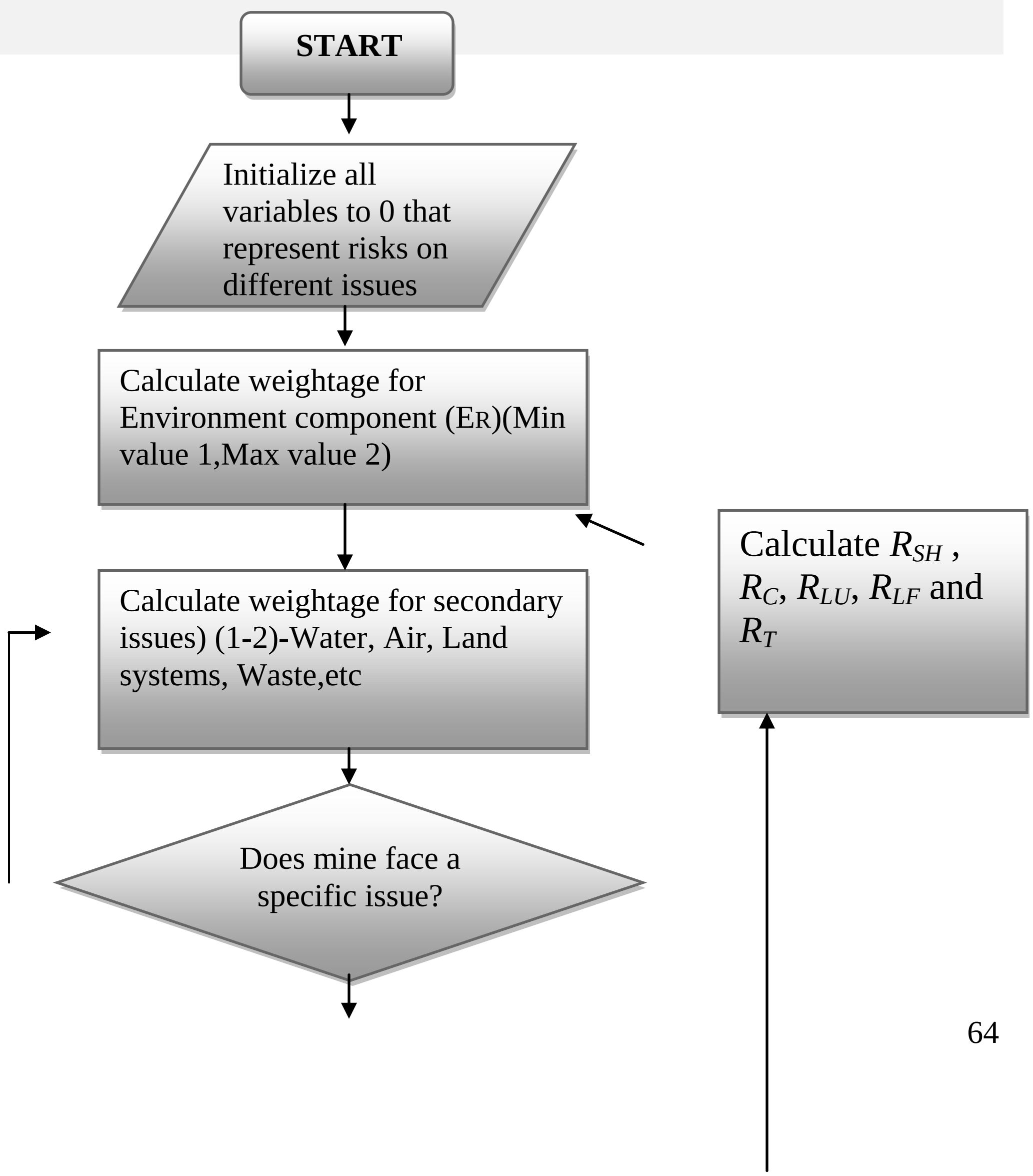
A similar process is used to calculate R_{SH} , R_C, R_{LU}, R_{LF} and R_T. The Closure Risk Factor is simply the summation of these components, i.e.

$$\mathbf{C}_{RF} = \Sigma(R_E + R_{SH} + R_C + R_{LU} + R_{LF} + R_T)$$

Table 3.5 Relationship between CRF and Closure risk rating

C_{RF}	Closure risk rating
> 2000	Extreme
1500-2000	Very high
1000-1500	High
500-1000	Moderate
<500	Minor

Flowchart for estimation of closure risk rating in a mine



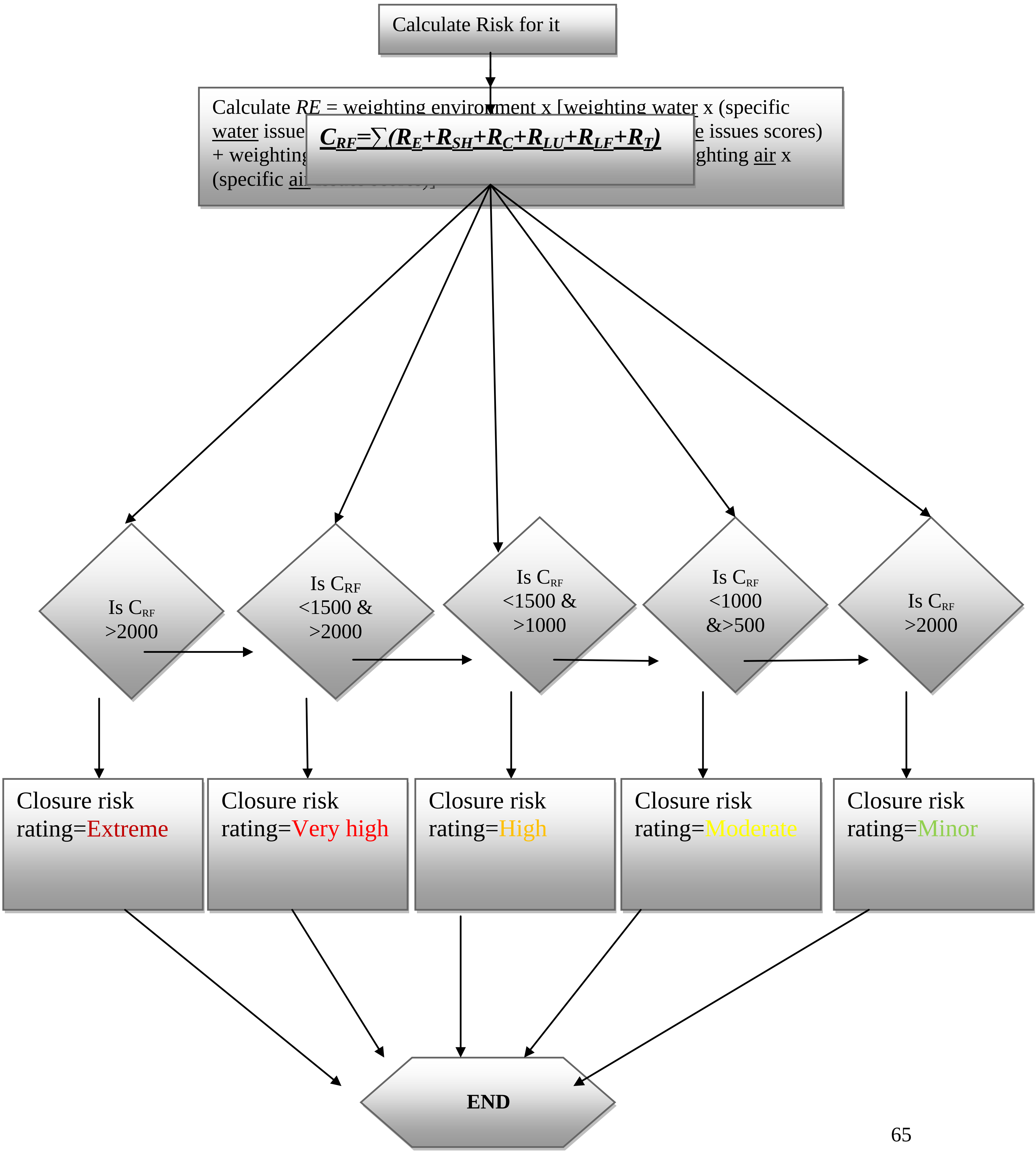
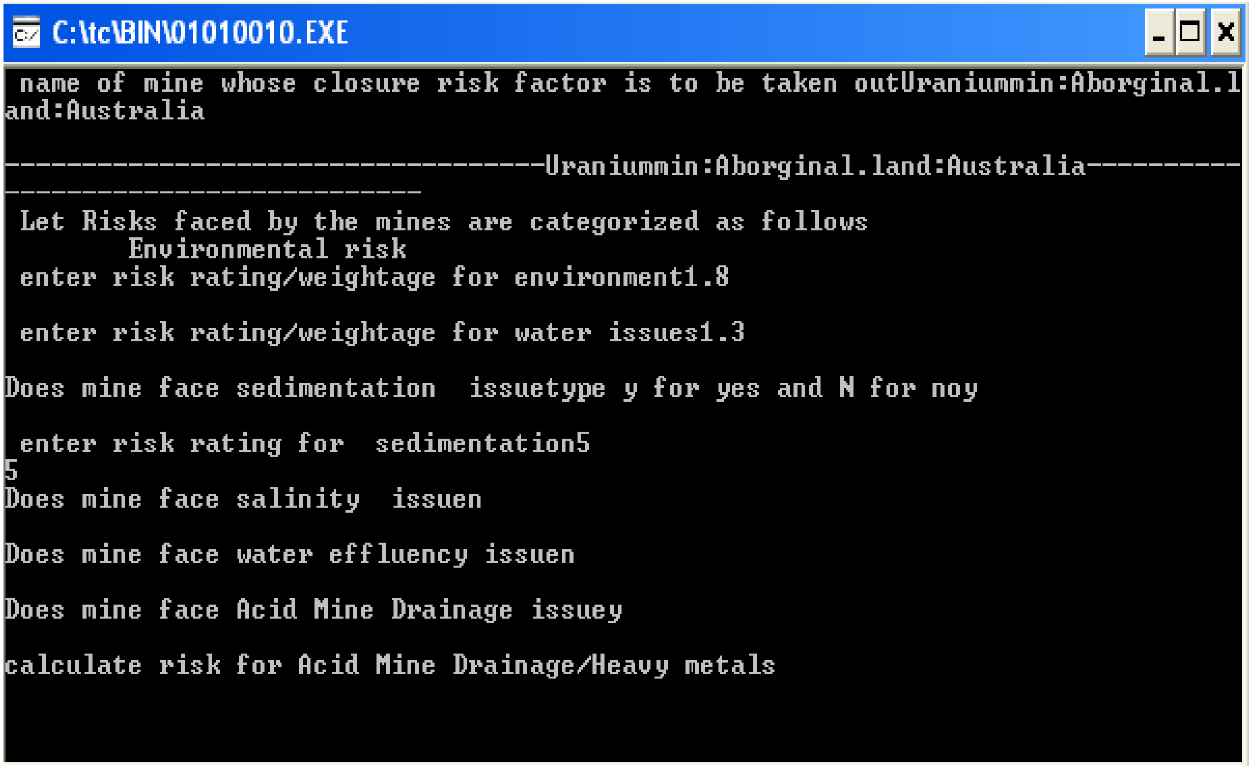
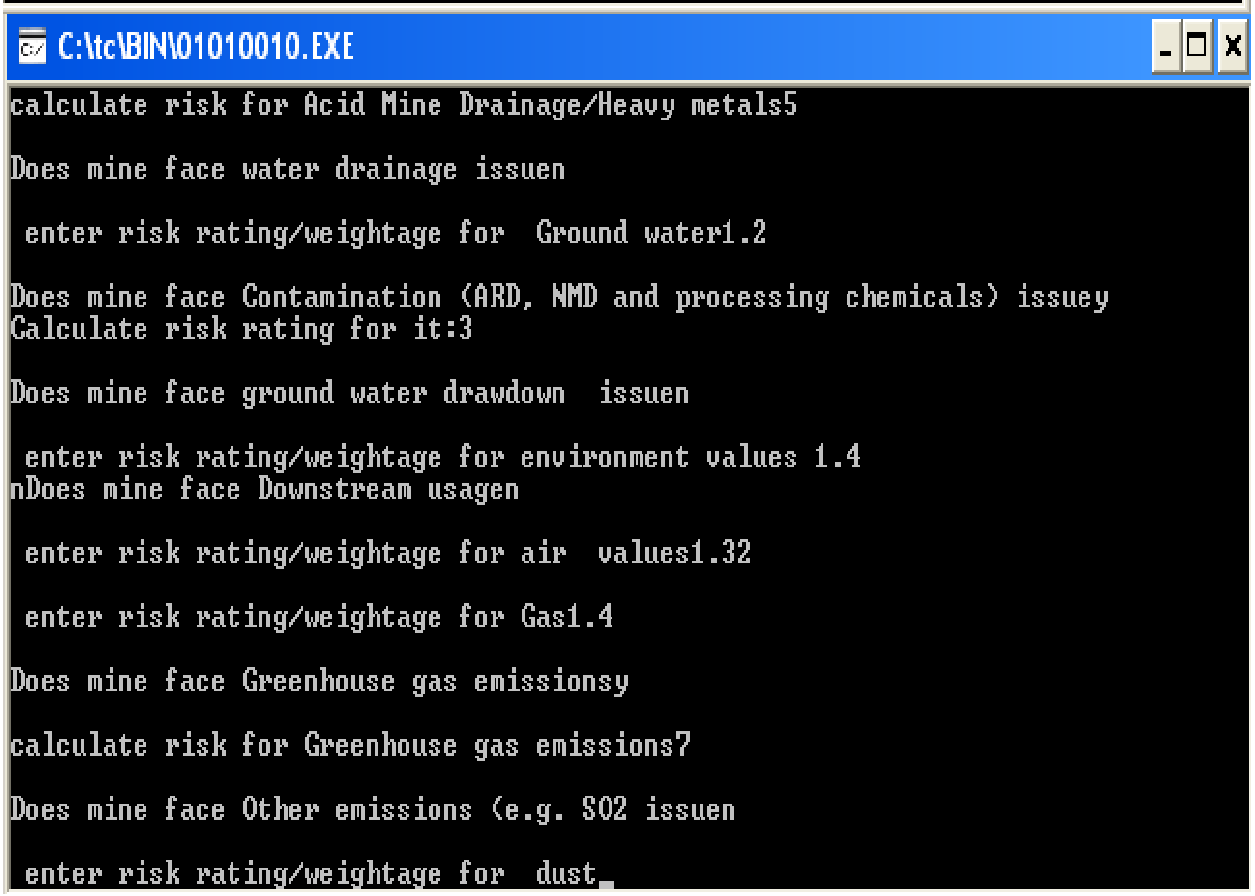

Calculate Risk for it
Calculate RE = weighting environment x [weighting water x (specific
water issue
+ weighting
(specific ai
e issues scores)
ghting air x
$C_{RF}=\sum(R_E+R_{SH}+R_C+R_{LU}+R_{LF}+R_T)$
Is C_{RF} >2000
Is C_{RF} <1500 & >2000
Is C_{RF} <1500 & >1000
Is C_{RF} <1000 &>500
Is C_{RF} >2000
Closure risk rating=Extreme
Closure risk rating=Very high
Closure risk rating=High
Closure risk rating=Moderate
Closure risk rating=Minor
END

Figure 3.4 Flowchart for computing Closure risk factor

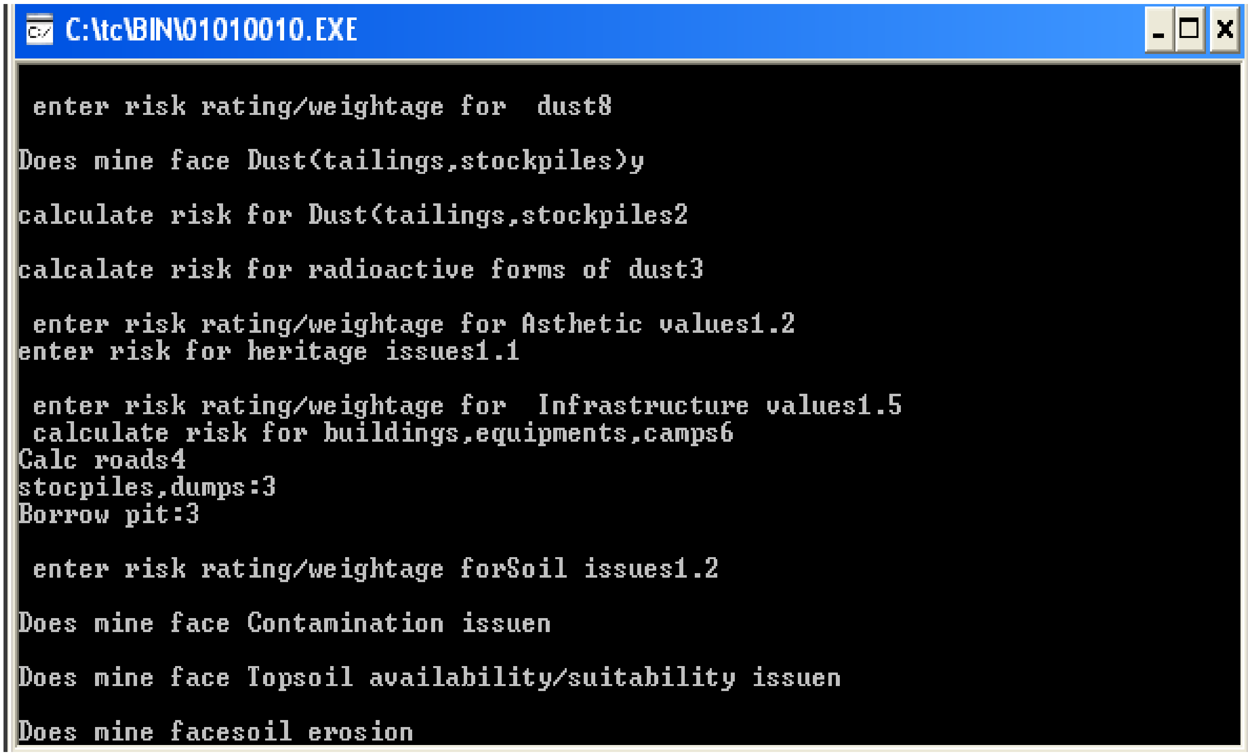
3.3.1Output

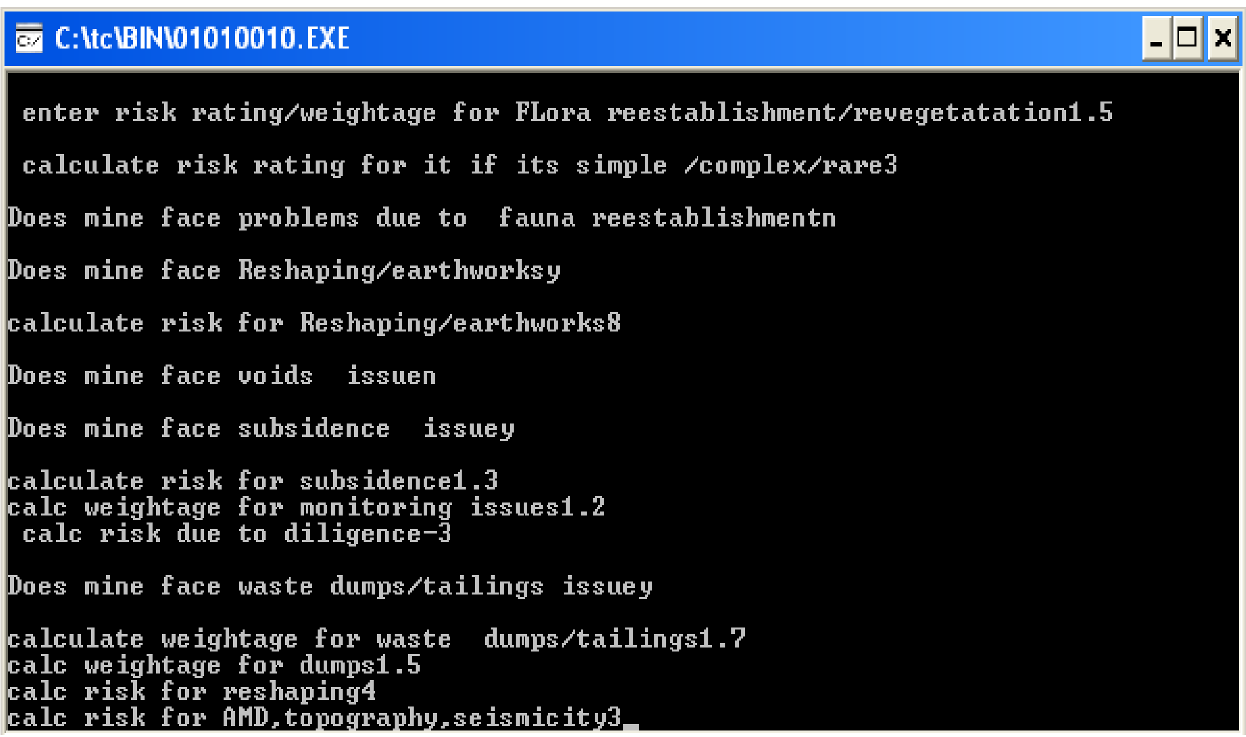


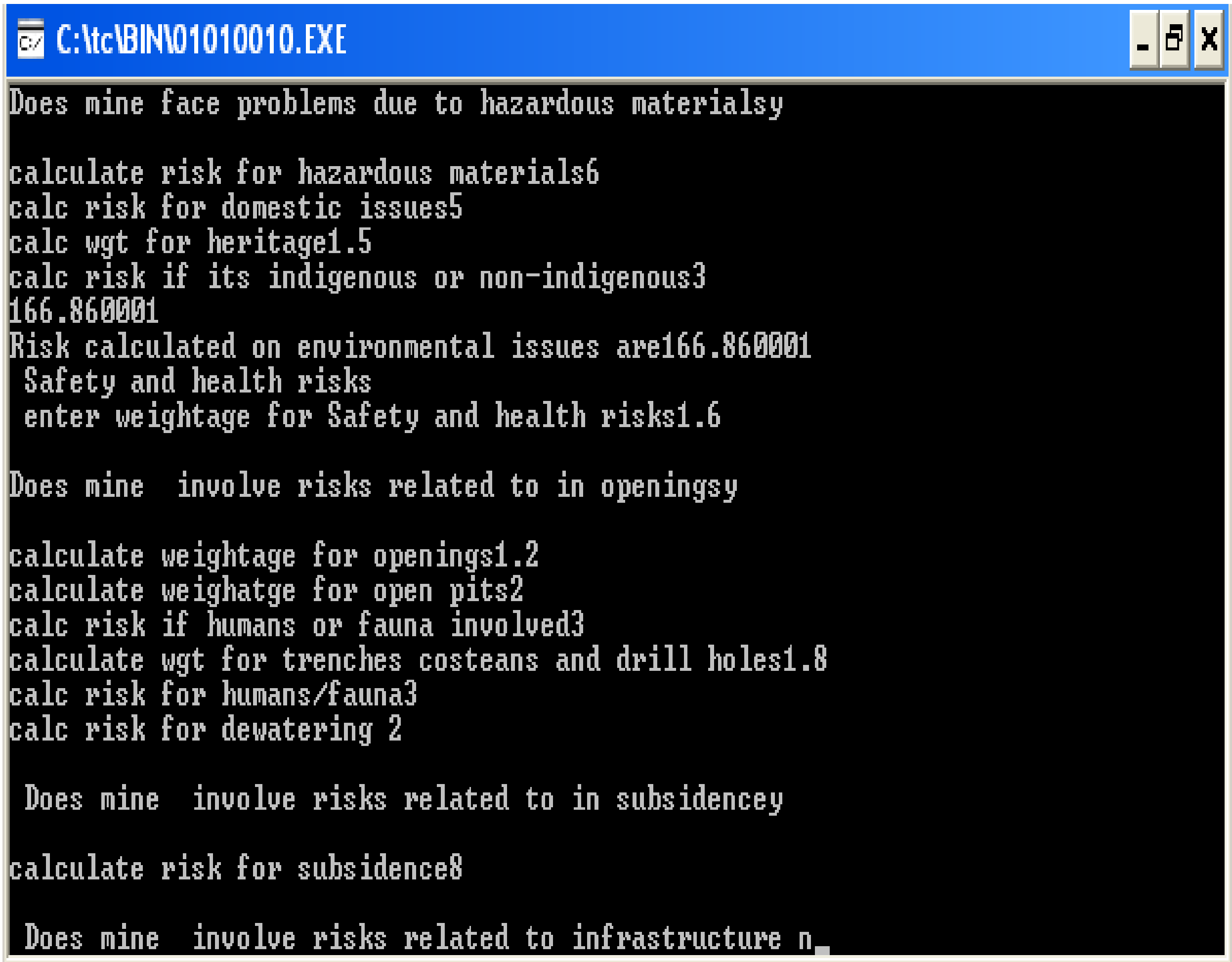
```
C:\tc\BIN\01010010.EXE
 name of mine whose closure risk factor is to be taken outUraniummin:Aborginal.l
and:Australia

-----------------------------------Uraniummin:Aborginal.land:Australia----------
---------------------------
 Let Risks faced by the mines are categorized as follows
        Environmental risk
 enter risk rating/weightage for environment1.8

 enter risk rating/weightage for water issues1.3

Does mine face sedimentation  issuetype y for yes and N for noy

 enter risk rating for  sedimentation5
5
Does mine face salinity  issuen

Does mine face water effluency issuen

Does mine face Acid Mine Drainage issuey

calculate risk for Acid Mine Drainage/Heavy metals
```

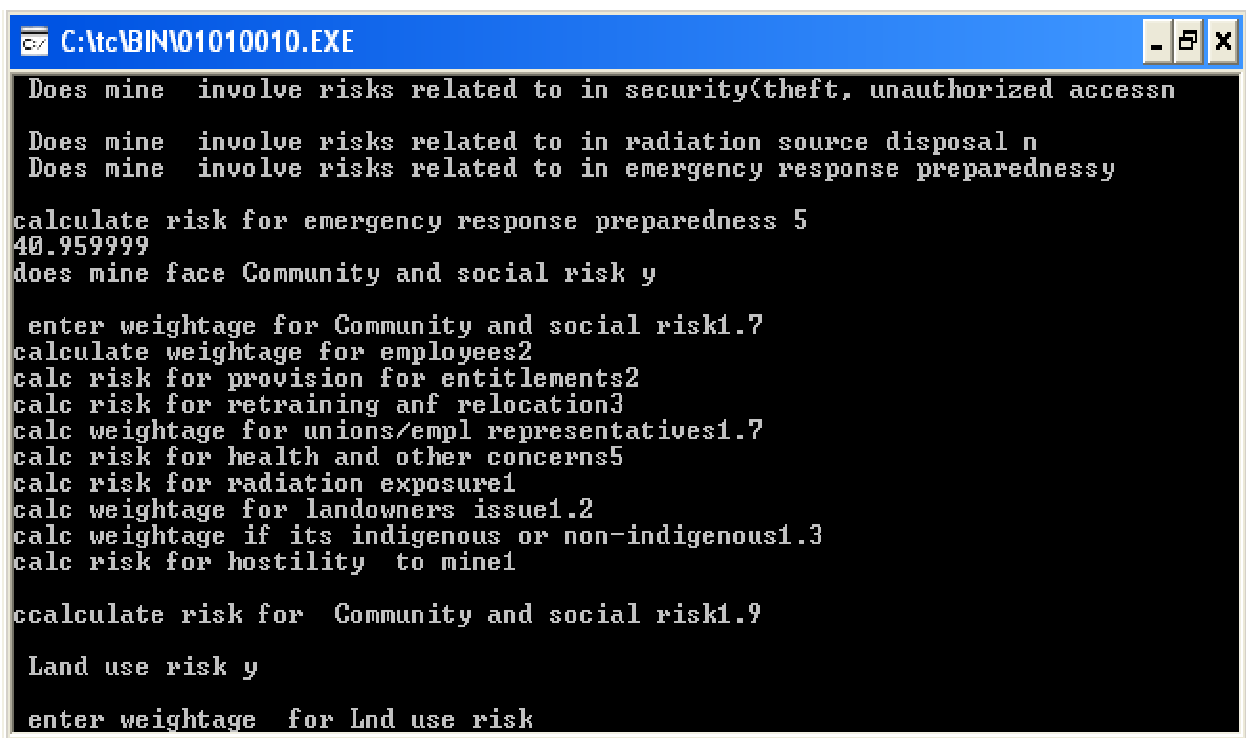


```
C:\tc\BIN\01010010.EXE
calculate risk for Acid Mine Drainage/Heavy metals5

Does mine face water drainage issuen

 enter risk rating/weightage for  Ground water1.2

Does mine face Contamination (ARD, NMD and processing chemicals) issuey
Calculate risk rating for it:3

Does mine face ground water drawdown  issuen

 enter risk rating/weightage for environment values 1.4
nDoes mine face Downstream usagen

 enter risk rating/weightage for air  values1.32

 enter risk rating/weightage for Gas1.4

Does mine face Greenhouse gas emissionsy

calculate risk for Greenhouse gas emissions7

Does mine face Other emissions (e.g. SO2 issuen

 enter risk rating/weightage for  dust_
```


C:\tc\BIN\01010010.EXE
enter risk rating/weightage for dust8
Does mine face Dust(tailings,stockpiles)y
calculate risk for Dust(tailings,stockpiles2
calcalate risk for radioactive forms of dust3
enter risk rating/weightage for Asthetic values1.2
enter risk for heritage issues1.1
enter risk rating/weightage for Infrastructure values1.5
calculate risk for buildings,equipments,camps6
Calc roads4
stocpiles,dumps:3
Borrow pit:3
enter risk rating/weightage forSoil issues1.2
Does mine face Contamination issuen
Does mine face Topsoil availability/suitability issuen
Does mine facesoil erosion

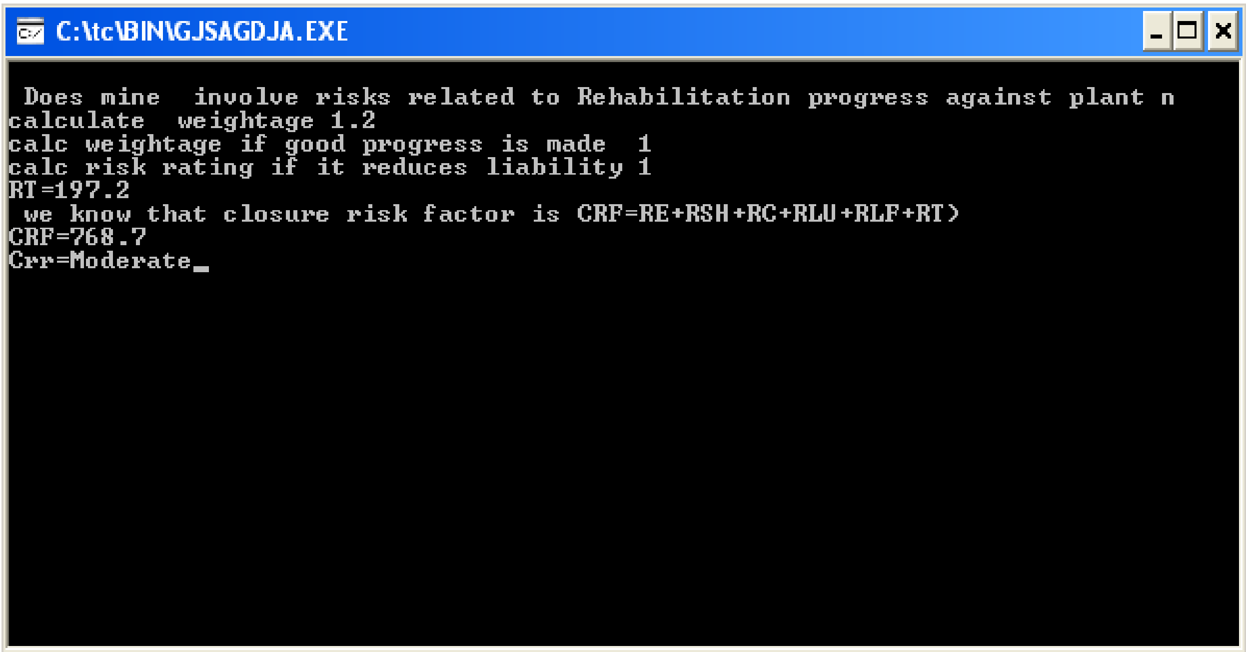

C:\tc\BIN\01010010.EXE
enter risk rating/weightage for FLora reestablishment/revegetatation1.5
calculate risk rating for it if its simple /complex/rare3
Does mine face problems due to fauna reestablishmentn
Does mine face Reshaping/earthworksy
calculate risk for Reshaping/earthworks8
Does mine face voids issuen
Does mine face subsidence issuey
calculate risk for subsidence1.3
calc weightage for monitoring issues1.2
calc risk due to diligence-3
Does mine face waste dumps/tailings issuey
calculate weightage for waste dumps/tailings1.7
calc weightage for dumps1.5
calc risk for reshaping4
calc risk for AMD,topography,seismicity3


C:\tc\BIN\01010010.EXE
Does mine face problems due to hazardous materialsy
calculate risk for hazardous materials6
calc risk for domestic issues5
calc wgt for heritage1.5
calc risk if its indigenous or non-indigenous3
166.860001
Risk calculated on environmental issues are166.860001
Safety and health risks
enter weightage for Safety and health risks1.6
Does mine involve risks related to in openingsy
calculate weightage for openings1.2
calculate weighatge for open pits2
calc risk if humans or fauna involved3
calculate wgt for trenches costeans and drill holes1.8
calc risk for humans/fauna3
calc risk for dewatering 2
Does mine involve risks related to in subsidencey
calculate risk for subsidence8
Does mine involve risks related to infrastructure n


C:\tc\BIN\01010010.EXE
Does mine involve risks related to in security(theft, unauthorized accessn
Does mine involve risks related to in radiation source disposal n
Does mine involve risks related to in emergency response preparednessy
calculate risk for emergency response preparedness 5
40.959999
does mine face Community and social risk y
enter weightage for Community and social risk1.7
calculate weightage for employees2
calc risk for provision for entitlements2
calc risk for retraining anf relocation3
calc weightage for unions/empl representatives1.7
calc risk for health and other concerns5
calc risk for radiation exposure1
calc weightage for landowners issue1.2
calc weightage if its indigenous or non-indigenous1.3
calc risk for hostility to mine1
ccalculate risk for Community and social risk1.9
Land use risk y
enter weightage for Lnd use risk

```
C:\tc\BIN\01010010.EXE
 enter weightage  for Lnd use risk1.4
enter weightage if its high/mid/low value5
calc weighatge if its agricultural land/ national park/ heritage1.9
cal risk for if its heritage2

calculate risk for Land use risk9

 Legal and financial  risk y

 enter weightage  for Legal and financial risk1.2

calculate weightage for if govn involved1.1
calc weighatge if title is retained sold or relinquihsed1
calc weightage if security or bonds are large/small1
calc risk for same5
calc weighate for creditors1.5
calc weigt for employees entitlement1.5
calc risk for same2
calc weightage for contractors fees1
calc risk for same1
calc weightage for buisnesses secrecy1
calc risk for same1
calc weightage for govn's taxes owning1
calc risk for same1
calc weigtage provision for rehabiliation
```

```
C:\tc\BIN\01010010.EXE
calc weigtage provision for rehabiliation1
calc weighatge for if provision is mad or note1
calc risk if provision is made for lower liability1
calc potaential for adverse publicity1
 calc weightage if there are protests1
calc risk of it effecting corporate image1
1

 Technical  risk
 enter risk rating for Technical risk1.3

 Does mine  involve risks related to closure planty

calculate  weightage1.2
calc weightage if plant utodate or not2
calc risk rating if its facilitates rehab2
calc weightage for closure team1.2
calc weightage if its managment related1.5
calc risk for getting good outcome2
calc weightage if its environment related1
calc risk rating for good outcome1

 Does mine  involve risks related to Exhaustion of resourcesn

 Does mine  involve risks related to Rehabilitation progress against plant_
```



Case Study 1: Uranium mine on aboriginal land surrounded by world heritage national park .The closure risk factor $C_{RF}=\sum(R_E+R_{SH}+R_C+R_{LU}+R_{LF}+R_T)$

R_E=537 R_{SH}=57.3 R_C 303.8 R_{LU}=64.0 R_{LF}=175.9 R_T=-94 So, C_{RF} 1044.0

According to table closure risk is Very high for Uranium mine.

Case Study 2:

Small scale extractive operation (for sand and gravel situated close to a major urban center). Here R_E=122.6, R_{SH}=28.4, R_C=45.1, R_{LU}=-5.2, R_{LF}=48, R_T=12.1.Thus,C_{RF} =251.0According to table closure risk here is minimum.

Case Study 3: Open pit Porphyry copper mine in the Pacific Rim

In this case R_E=1237.2, R_{SH}=106.7, R_C=589.6,R_{LU}=37.4,R_{LF}=40.5,R_T=42.9

CRF=2054.3(According to table here Closure risk is Extreme here)

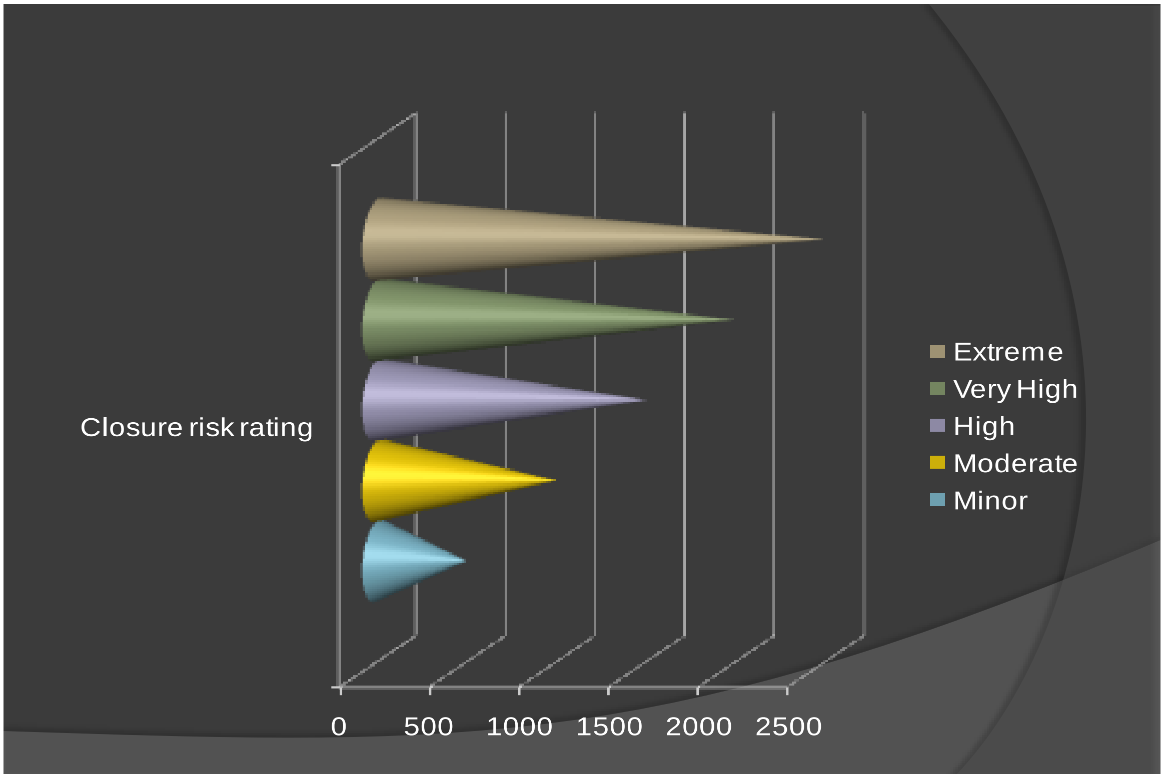


Fig 3.5: Graph depicting various levels of Closure risk for above mines

3.4 A CASE STUDY OF RISK ASSESSMENT AND RISK MANAGEMENT AT TALCHER COLLIERY, MCL

The steps we would be following for for risk assessment and risk management in Talcher Colliery are as follows:-

- Hazards identification
- Ranking of hazards as per their probability, consequence and exposure
- Management of hazards as per their ranking

The risk assessment and risk management of Talcher Colliery is as below:-

3.4.1 *Hazards identifications*

- Fire/spontaneous heating
- Inundation
- Explosion
- Roof/Side fall
- Haulage/Locomotive
- Conveyor systems
- Electrical
- Heat and Humidity
- Effectiveness of evacuation of work person through upcast shaft.
- Shaft Drainage
- Emergency Exit through coal winder/skip
- Travelling through loco roadways
- Inspection route of Isolation stopping
- Explosives and Blasting
- Underground gas cutting operations

3.4.2 Calculation of risk for the hazards that were identified

1) Risk Assessment

1) Fire/Spontaneous heating
a) Consequence - Catastrophe – 100
b) Exposure - Once in 10 years - 0.5
c) Probabability - Unusual but possible – 3 Risk Assessment Points 100 x 0.5 x 3 = 150

2) Inundation

a) Consequence - Catastrophe - 100
b) Exposure - Occasional - 2
c) Probability - Practically Impossible - 0.5   Risk Assessment Points 100 x 2 x 0.5 = 100

3) Explosion

a) Consequence - Catastrophe - 100
b) Exposure - Once in 100 years - 0.02
c) Probability-Practically impossible-0.50 Risk Assessment Points 100 x 0.02 x 0.05 =0.1

4) Roof//Side fall

a) Consequence - Disaster - 40
b) Exposure - Daily - 05
c) Probability - Between remotely possible and Conceivable but unlikely - 01.5
Risk Assessment Points 40 x 5 x 1.5 = 300

5) Haulage/Locomotive

a) Consequence - Very serious - 15
b) Exposure - Daily - 05
c) Probability - Remotely Possible - 02
Risk Assessment Points 15 x 5 x 1 = 150

6) Conveyer systems

a) Consequence - Serious - 05
b) Exposure - Daily - 05
c) Probability - Conceivable but unlikely – 01 Risk Assessment Points 5 x 5 x 1 = 25

7) Electricals

a) Consequence - Serious - 05
b) Exposure - Daily - 05
c) Probability - Conceivable but unlikely – 01 Risk Assessment Points 5 x 5 x 1 = 25

8) Heat and Humidity

a) Consequence - Minor - 2
b) Exposure - Unusual (Monthly) - 2.5
c) Probability - Conceivable but unlikely– 01 Risk Assessment Points 2 x 2.5 x 1 = 5

9) Effectiveness of Evacuation of work persons through upcast Shaft

a) Consequence - Catastrophe - 100
b) Exposure - Occasional - 2
c) Probability - Practically impossible - 0.5   Risk Assessment Points 100 x 2 x 0.5 = 100

10) Shaft Drainage

a) Consequence - Catastrophe - 100.0
b) Exposure - Once in 10 years - 0.5

c) Probability - Conceivable but unlikely - 01.0isk Assessment Points 100 x 0.5 x 1 = 50

11) Emergency Exit through Coal Winding/Skip

a) Consequence - Serious - 05
b) Exposure - Between monthly and yearly - 2.25
c) Probability-Conceivable but unlikely-1.00Risk Assessment Points 5 x 2.25 x 1 = 11.25

12) Travelling roadway through locomotive roadway

a) Consequence - Very Serious - 15
b) Exposure - Daily - 5
c) Probability - Conceivable but unlikely – 1 Risk Assessment Points 15 x 5 x 1 = 75

13) Inspection route of isolation stopping

a) Consequence - Very serious - 15
b) Exposure - Weekly – 3
c) Probability - Conceivable but unlikely – 1 Risk Assessment Points 15 x 3 x 1 = 45

4) Explosions and blasting

a) Consequence - Disaster - 40
b) Exposure - Daily – 5c) Probability - Practically impossible - 0.5

Risk Assessment Points 40 x 5 x 0.5 = 100

15) Underground gas cutting operations

a) Consequence - Serious - 5
b) Exposure - Monthly - 2.5
c) Probability - Conceivable but unlikely – 1 Risk Assessment Points 5 x 2.5 x 1 = 12.5

Table 3.2 Risk Assessment of Talcher Colliery

Sl.No	Hazard	Points	Rating	Rank
1	Fire/Spontaneous Heating	150	37.5%	II
2	Inundation	100	25%	III
3	Explosion	0.1	25%	XIII
4	Roof and side fall	300	75%	I
5	Haulage/Locomotive	150	37.5%	II
6	Conveyor System	25	6.1%	IX
7	Electricals	25	6.1%	IX
8	Heat and Humidity	05	1.25%	XII
9	Effectiveness of evacuation of work person through U.C. shaft	100	0.25%	III
10	Shaft Drainage	50	12.25%	VI
11	Emergency Exit through Skip	11.25	25 2.8%	XI
12	Travelling through loco roadway	75	18.25%	V
13	Inspection route of isolation Stopping	45	11.25%	VII
14	Explosive and Blasting	100	25%	IV
15	Underground gas cutting	12.5	3.05%	X

RISK MANAGEMENT

The following procedure is good guide to manage the risk .They are:-

- Elimination
- Substitution
- Separation
- Training
- Administration
- Personal Protective Equipments

As per the risk assessment of Talcher colliery the 4 major risks as per ranking are

- Side fall
- Effectiveness of evacuation of work person through U.C. shaft
- Haulage and Roof and Locomotive
- Explosive and blasting

The assessment, present procedure and management for present hazards (only top 4)are done below.

Table 3.3 Roofs and side fall

Assessment	Present Procedure	Management
Supply of support material	Assessment of support material as per targeted production is done	Administrative co-ordination in procurement of support material by various controlling agency on time
Provision of support personnel	A through study for deployment of personnel already done	Elimination by use of remote control drills, substitution by means of mechanical drilling machines
Proper supervision	Negligence in supervision to be strictly dealt with	--------------
Training	Counseling by district in charge and safety officer	Improving skills by special workshop and training

Support designing	Design of support system for each panel done as RMR and duly approved by DGMS	Design substitution for change of RMR to be studied for various in-situ geological phenomena
Quality control	Quality of supports monitored	To be checked by anchorage testing at various stages

Table 3.4 Fires and spontaneous heating

Assessment	Present procedure	Management
Conditions favorable for fire and spontaneous heating	Weekly monitoring and proper ventilation	Elimination by cleaning of coal in 27^{th} area and 5nw
Personal protective equipment	Self rescuer provided	Self contained rescuer to be provided
Supervision by competent person	Done once in a week and record maintained	Continous site monitoring to be done by modern methods
Organisation to deal with fire	Proper procedure for dealing with fire/safe withdrawal of persons have been framed	Training and mock rehearsal ofpersons to keep th eperson informed about the procedure
Communication	Simex provided but nit effective during power failure	A more reliable and DMGS approved type of communication system to be provided

Table 3.5 Effectiveness of evacuation of persons through U.C. shaft

Assessment	Present procedure	Management
Man winding in U.C shaft	------------------------	Elimination by providing an incline as intake
In adequate arrangement of evacuation of persons by skip winding	Temporary arrangement being made to lift persons by skip in cases of breakdown by lift	Subsitutuion by means of a skip by proper man winding facilities

Table 3.6 Haulage and Locomotive

Assessment	Present procedure	Management
Old and obsolete locomotive	Safety devices of locomotive not proper	Substitution with new locomotives and replacement of old ones
Re-railment of derailed mine cars	Manual means	Separation by means of mechanical devices to be studied and implemented
Locomotive Roadway	Old supports being replaced and widening heightening of galleries done	Trolley wire to be firmly installed and maintained at uniform height
Uncontrolled movement of mine cars	Loose shunting at pit bottom and landline	Elimination by providing double track landline at pit bottom and landline
Coupling drawbar, buffer	Approved type being used	Substandard coupling drawbar buffer not to be used
Travelling along loco-roadways	Danger boards and manhole provided	Elimination by providing travelling roadways separated by loco roadway

Table 3.7 Risk rating at Talcher Colliery

Sl.no	Seam	A	B	D	E	F
1	Hazards	-------	-------	10	01	09
2	,,	-------	04	-------	14	02 & 03
3	,,	-------	-------	05	12%1	-------
4	,,	-------	-------	06	7,11 &15	-------
5	,,	-------	-------	06	08	-------

CHAPTER 4

4. CONCLUSION

Safety and environmental risk assessment is sine quo non for ensuring mine and miners safe .It is necessary to assess the risk from different mining operations and take cost effective suitable measures to prevent, eliminate and minimize risk. Both qualitative and quantitative risk approaches can is followed to assess the risk level. Risk analysis techniques like FTA, ETA and HAZOP etc can be used as tools as study and understanding the risk levels more effectively and can aid in risk prevention and control.

It was perceived during the study of the project that the present condition of mine environment and safety risk' is at a low. It was found that mine risk assessment techniques and implementations are more popular in the developed nations like Australia, USA, Canada, European countries etc. and are yet to gain a definite and precise foothold in the Indian mining scenario. Some Indian mines are employing risk assessment techniques although much work has to be done in terms of successful application and identifiable results. It the 9th and 10th Safety Conferences held in New Delhi as well draft Coal Mines Regulations, 2006, emphasis is being laid to conduct safety risk assessment and management in mines. Thus, it is statutorily mandatory to conduct safety risk assessment using suitable risk assessment methodology. Further, as per ISO-14010, mining companies have to conduct environment audit for environmental compliance. It is thus pertinent to carry out both safety and environmental risk assessment with due diligence to minimize risk to miners and make mine environmentally sustainable and friendly.

Fault Tree+11 analysis programs for Microsoft Windows enables us to analyze the availability and reliability of both complex and simple systems and is easy and intuitive to use. Fault Tree+ 11 provides an integrated environment for performing fault tree analysis, event tree analysis and Markov analysis. In this case mine fire is modeled using fault tree. A program for estimation of spontaneous fire risk potential in underground mines is carried out using TURBO C++ using

Linux as the platform. The program is user friendly and can help in classifying Bord and Pillar workings into low/high/very high category. Another program was developed in TURBO C++ to compute closure risk factor for mines and to evaluate risk category based on the concept proposed by Laurence (2002). Data was also collected from MCL mines to assess and quantify safety risk and suggest appropriate risk management. Risk assessment and management for ensuring better safety at work place and eliminating health hazards in the mining industry is an important tool for assessment, prioritize and control hazards. Conduct of environmental and safety risk assessment in Indian mines is new and lacks expertise; hence effort is made by different mining companies and statutory agencies to train man power in this field to make risk assessment scientific, prudent and realistic and a fruitful exercise so that suitable corrective actions can be taken in a timely manner to minimize the hazards.

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